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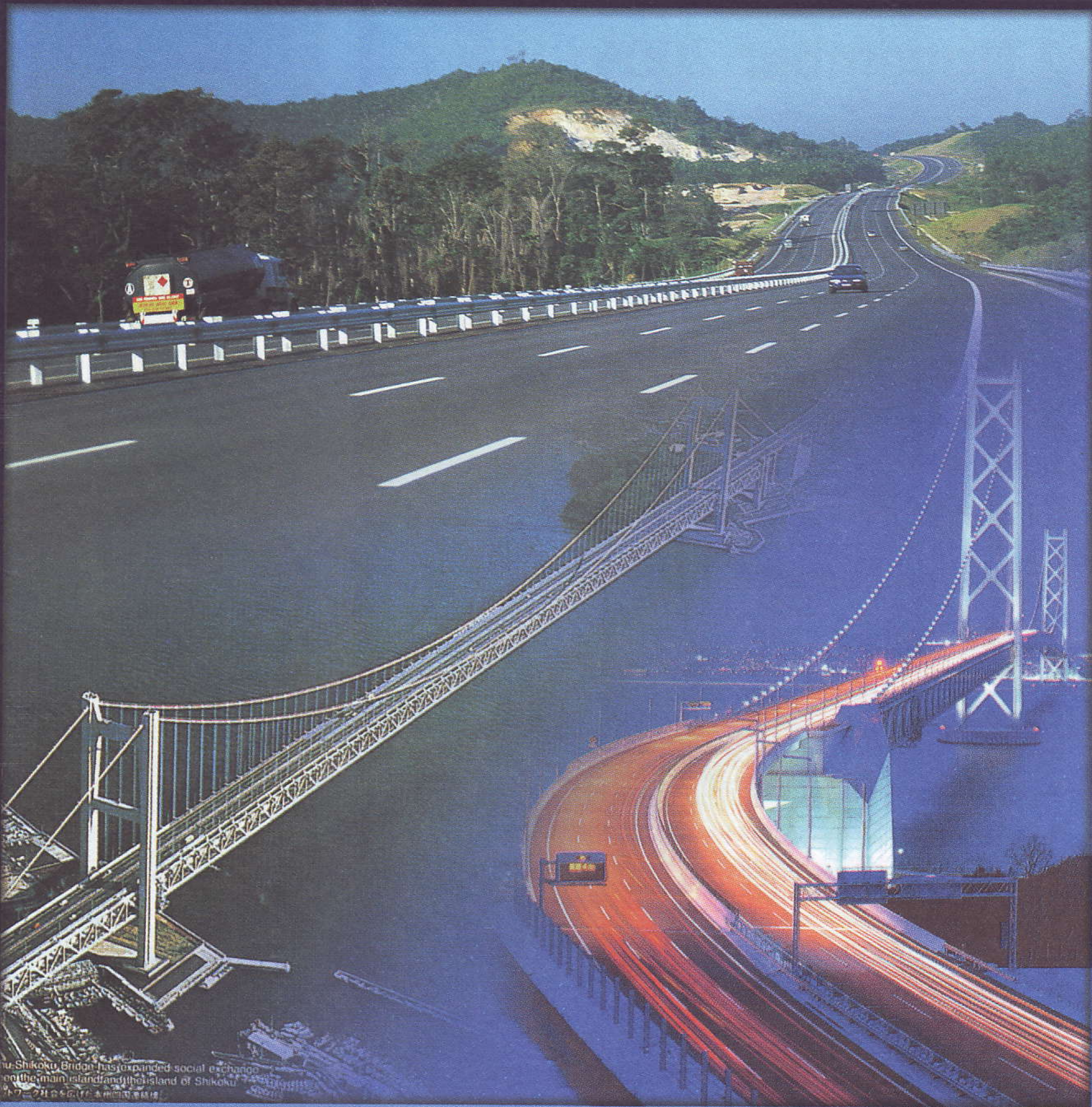

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Editorial

This first issue of the REAAA Journal for 2006 contains five papers.

Specifications and contract documents for pavement construction in Japan have been revised to take account of the move away from empirical pavement design procedures towards mechanistic, or structural, procedures. The introduction of performance-based specifications has led to an increase in the demand for full-scale accelerated pavement (APT) testing for both proof testing of proposed designs and the evaluation of new pavement materials and/or technologies. The Public Works Research Institute of Japan has recently commissioned a reciprocal (linear) APT device and updated its circular facility. This paper provides some background into the development of performance based specifications in Japan and presents details of its two APT facilities. The need for on-site testing may also increase as the trend toward performance-based specifications increases. The next step, therefore, should be the development of a mobile facility.

Surface texture is the single most important physical characteristic in the management of chip seal surfacings because it is directly related to skid resistance. The development of a method that allows road owners and contractors to enhance the accuracy, reproducibility, and speed of texture measurement task will therefore accrue a large number of benefits, not only to road managers but also to the community. The purpose of the research described in this paper from New Zealand was to evaluate whether a practical method of road surface texture measurement using digital image processing, incorporating information theory and fast Fourier transform analysis, could be developed. The results of trials in the USA and New Zealand clearly demonstrated that the merger of digital image processing and physical texture measurements was possible and had the potential to successfully replace the sand circle (sand patch) test currently used. It was also possible to standardise the experimental set-up and calibrate the software and hardware necessary to achieve a high correlation using non-linear regression analysis with a sorted sample population. It is also proposed that the results of this research could be extended beyond texture measurement to the characterisation of skid resistance.

This paper won the New Zealand Road Innovation Award 2005. The prize is awarded annually by Transit New Zealand and Works Infrastructure Ltd for most innovative paper.

The third paper describes a collaborative research and development project between Griffith University, SMEC Australia and six Local Government Authorities in Southeast Queensland. The main purpose of the project is to calibrate the pavement deterioration factors that are required by the HDM-III deterioration models that have been integrated within the SMEC pavement management system. This paper presents an overview of the research conducted to date, including the procedure for the selection of the Southeast Queensland long term pavement performance (LTPP) sites and the rationale behind the design of the site selection matrix. The pavement distress progression generated by the HDM-4 deterioration models will be compared with those predicted by the calibrated HDM-III models in the next phase of the study. Details of the modelling of pavement deterioration using HDM-III at two selected sites are also presented in this paper.

At the 4th meeting of the Heads of Road Authorities (HORA) held in Bangkok, Thailand, in June 2005, each participating country was invited to give a short presentation on their local experiences with the privatisation of road facilities and problems they were facing. This paper presents a summary of these presentations, including the types of schemes operating and problems associated with their use. Many countries expressed the hope that, through REAAA, all countries will benefit from an exchange of information between member countries as a means of improving their knowledge and experience in the privatisation of road facilities.

During October 2005, young professionals representing State Road Authorities in Australia and New Zealand toured several European countries to discuss and inspect the latest traffic management techniques and systems in these countries. The focus of the trip was the task of operating the road system and the initiatives that are being used to maximise the efficiency of the network. This paper presents a summary of the findings of the tour. It is suggested that a number of initiatives could be considered for adoption in the region if not already implemented. This paper is based on a report prepared for, and presented to, Austroads Council in March 2006.

The Editorial Panel continues to seek papers and technical notes for publication in the Journal. The membership of the Editorial Panel follows. REAAA members interested in submitting a paper should seek advice from the appropriate member(s) of the Editorial Panel. The Panel is striving to publish at least one paper from each Chapter or region each year.

Kieran Sharp
Chairman REAAA Technical Committee

MEMBERSHIP OF EDITORIAL PANEL: REAAA JOURNAL

THE USE OF ACCELERATED PAVEMENT TESTING TO SUPPORT THE INTRODUCTION OF PERFORMANCE BASED SPECIFICATIONS IN JAPAN

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ABSTRACT

Specifications and contract documents for pavement construction in Japan have been revised to take account of the move away from empirical pavement design procedures towards mechanistic, or structural, procedures. Since the release of the *Technical Standards for Structures of Pavements* in 2001, the use of performance-based specifications has been increasing. The introduction of performance-based specifications has led to an increase in the demand for full-scale accelerated pavement (APT) testing for both proof testing of proposed designs and the evaluation of new pavement materials and/or technologies. As the public research and consultancy entity for road agencies, the Public Works Research Institute has recently commissioned a reciprocal (linear) APT device and updated its circular facility. This paper provides some background into the development of performance based specifications in Japan and presents details of its two APT facilities. The need for on-site testing may also increase as the trend toward performance-based specifications increases. The next step, therefore, should be the development of a mobile facility.

1. INTRODUCTION

Specifications and contract documents for pavement construction in Japan have recently been revised to take account of the move away from empirical pavement design procedures towards mechanistic, or structural, procedures. One advantage of mechanistic design is that innovative technologies, which might be rejected by empirical design methods, can be considered as an alternative design. As a result of the release of the *Technical Standards for Structures of Pavements* (Ministry of Land, Infrastructure and Transport 2001; Japan Road Association 2001), the use of performance-based specifications in Japan has been increasing.

With the introduction of performance-based specifications, the demand for full-scale accelerated pavement testing (APT) for both proof testing of proposed designs and the evaluation of new pavement materials and/or technologies has been increasing.

The Public Works Research Institute (PWRI) is the public research and consultancy entity for the Japanese road agencies. A linear APT facility has been commissioned by the PWRI to supplement the existing circular facility. The circular facility has also recently been upgraded, including new loading vehicles and control system.

This paper presents a description of the two facilities and a brief summary of the characteristics of the facilities. The terms used for the facilities in this paper are C-APT (Pavement Test Field – the circular test facility) and R-APT (Pavement Test Facility for Recycled Materials – the reciprocal (linear) facility) respectively.

2. REFORM OF PAVEMENT SPECIFICATIONS IN JAPAN

Specifications and contract documents for pavement construction in Japan have recently been changed from recipe- or method-based specifications to performance-based specifications (Yoshida 2001). The means that the form of the contract has changed, with the required performance of the final product now being specified. This in turn means that the primary indicators of quality are no longer based on materials testing in the laboratory but final site characteristics.

2.1 Performance-based Specifications

As illustrated in the second-left column of *Figure 1*, most contracts stipulate traditional design methods, materials, and procedures as empirically confirmed performance indicators. This is typical of a recipe-based specification. The new Japanese standard (Ministry of Land, Infrastructure and Transport 2001) requires quantitative values for fatigue,rutting,

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evenness (roughness) and permeability as performance inspection items after construction. For example, requirements for fatigue and rutting performance are shown in Table 1 and Table 2 respectively. In these Tables, the number of load cycles is expressed in terms of the number of 49 kN equivalent single-axle loads at pavement failure.

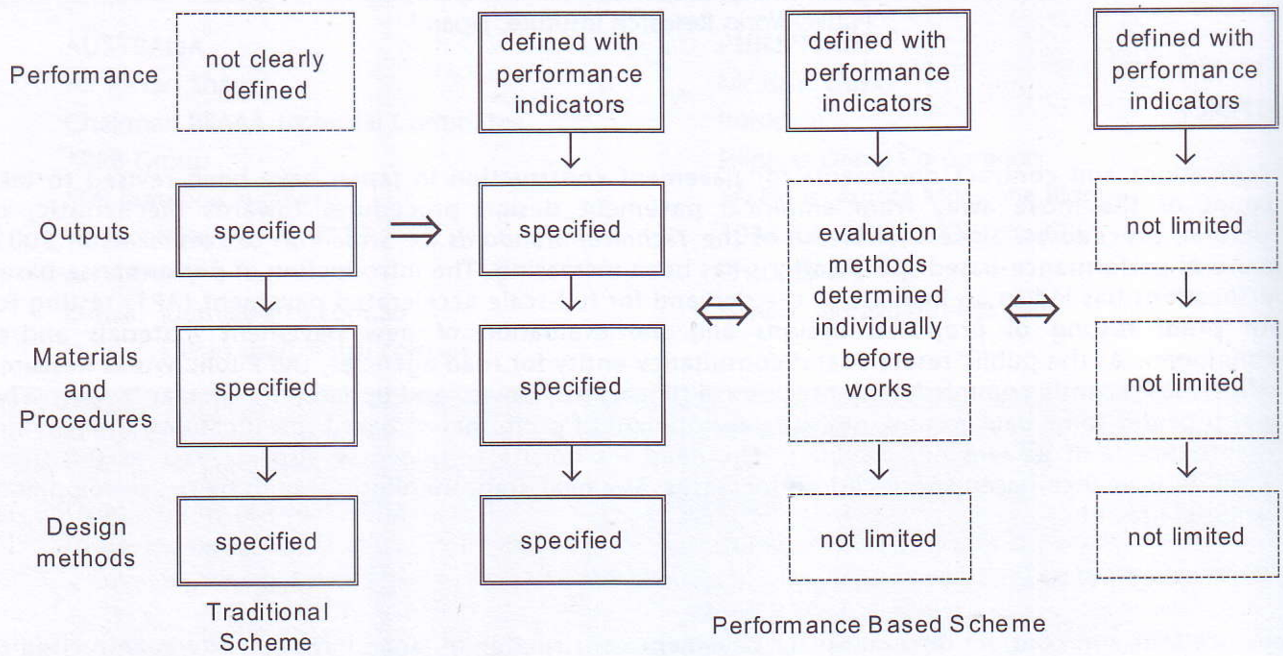


Figure 1: Transition from traditional scheme to performance-based scheme (Yoshida 2001)

In terms of confirming pavement performance, the standard (Ministry of Land, Infrastructure and Transport 2001) and its commentary (Japan Road Association 2001) stipulates that the following testing be conducted to confirm fatigue and rutting performance:

- insitu proof testing using mobile APT equipment
- experimental confirmation by observation of the field performance of the same pavement structure
- confirmation of proposed pavement structure through case studies
- recipe-based specifications for asphalt and Portland cement concrete pavements.

The first two items are based on actual experimental validation, whilst the last two items are based on experience with existing pavements. On-site inspection based on the first item is not possible because mobile APT facilities have yet to be introduced into Japan. Therefore, performance evaluation based on the second point is the only practical method available for the evaluation of new materials and/or processes. As the regulation also requires proof testing in the same condition as the proposed pavement, full-scale evaluation using APT is an ideal way of meeting these requirements.

Table 1: Number of Wheel Passes Causing Fatigue Failure (Ministry of Land, Infrastructure and Transport)

Design Traffic Volume (heavy vehicles/day)	Number of Wheel Passes Causing Fatigue Failure (passes over 10 years)
≥ 3000	3.5×10^7
1,000-3,000	7×10^6
250-1,000	1×10^6
100-250	1.5×10^5
< 100	3×10^4

Table 2: Number of Wheel Passes Causing Plastic Deformation
(Ministry of Land, Infrastructure and Transport)

Category	Design Traffic Volume (heavy vehicles/day)	Number of Wheel Passes Causing Plastic Deformation (passes / mm)
expressway	≥ 3000	3,000
trunk road	< 3,000	1,500
other		300

3. USE OF ACCELERATED PAVEMENT TESTING AT PWRI

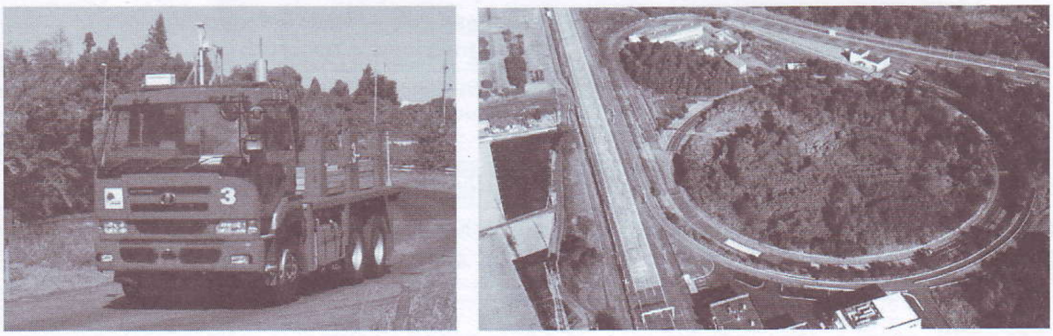
3.1 General Details of Accelerated Pavement Testing Facilities

The circular APT facility has been operating for about a quarter of a century whilst the linear facility was commissioned in 2001 to meet increasing demands for testing of new types of pavement such as those using recycled materials. Details of both facilities are presented in *Table 3* whilst a general view of both facilities, including the test vehicles and test track, is shown in *Figures 2* and *3*.

In terms of applied load C-APT can apply rear single axle loads up to 78.4 kN and front axle load up to 19.6 kN. The cycle time of the R-APT is 25 seconds and that of each vehicle operating on the C-APT is 57 seconds (short-loop). The estimation is based on the assumption that the facility operates 12 hours per day. The approximate number of days of operation required to apply typical traffic volumes on in-service pavements is shown in Table 4. The operational periods shown in italic in the Table are impractical because of their length. Considering that the period of operation is usually less than one year, these facilities can only estimate the performance of pavements when the traffic volume is less than or equal to 1,000 heavy vehicles per day.

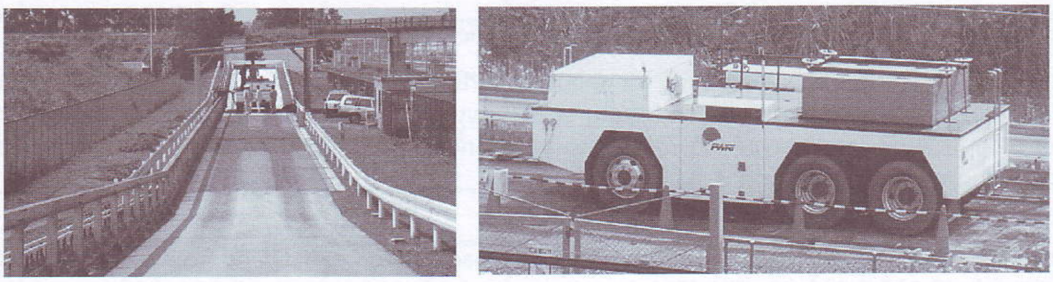
Table 3: Details of PWRI Accelerated Pavement Testing Facilities

	Circular APT (C-APT)	Reciprocating APT (R-APT)
commissioned	1979, 2004 (upgrade)	2001
cost	approx. US$2.3M	approx. US$0.8M
Pavement Configuration		
test length	870 m (long-loop) 628 m (short-loop)	60 m
wheelpath width	5 m	4 m
housing	outside	outside
environmental control	none	none
measurement instrumentation	n.a.	n.a.
Load Configuration		
wheel configuration	loading vehicle with rear double axle load (4 vehicles operate simultaneously)	loading vehicle with rear double axle load
loading vehicle weight	110–393 kN (each vehicle)	90-250 kN
wheel suspension	steel spring	steel spring
test speed	40 km/h (max.)	30 km/h (max.)
transverse distribution of load	±0.25 m	±0.25 m
load propulsion	truck loading	truck loading
power drive to wheel	diesel engine	electric motor (75 kV) driven hydraulic pump



Test Vehicle — Aerial View of Test Track

Figure 2: Circular APT (C-APT)



Test Track — Test Vehicle

Figure 3: Reciprocating (linear) APT (R-APT)

Table 4: Design Traffic Volume Classification and Approximate Operation Period

	Required Operational Period	
Heavy Vehicle Volume (vehicle/day/direction)	Circular APT (C-APT)	Linear APT (R-APT)
< 100	3 days	7 days
100-250	13 days	36 days
250-1,000	87 days	238 days
1,000-3,000	*607 (1.66 years)*	*1,667 (4.57 years)*
≥ 3000	*3,037 (8.32 years)*	*8,337 (22.8 years)*

* *Full load condition for both APT devices, Axle load conversion using 4th power law.*

3.2 Details of Reciprocating (Linear) APT (R-APT)

The reciprocating (linear) APT facility is a full-scale pavement tester in which a self-propelled loading vehicle runs reciprocally on a test track (see *Figure 4*). The system comprises a linear test course, loading vehicle, contact-less electric power supply system, and an operations room with a computerized control system.

The length of the test track over which the vehicle operates is 160 meters. The test pavements are constructed along the middle 50 metres of this length of this section and all experimental data is collected in this 50 metre long section.

Acceleration/deceleration slopes at both ends of the test course act as stabilising zones for the loading vehicle. The gradient of the slope is approximately 7/100 and was designed to take account of the acceleration and deceleration required when the loading vehicle is travelling at a speed of 30 km/h.

3.2.1 Loading Vehicle

The loading vehicle is a remodelled trailer cab which has the same facilities as a normal truck (steel frame structure, three-axial 10-tyre layout, suspension links, braking systems, steering assemblies, etc.). The rear tyre axles propel the vehicle utilising the energy generated on the slopes.

The loading vehicle is 6,510 mm long, 2,500 mm wide and 2,127 mm high. The two linkage rods connected the loading vehicle and accompanying carriages function as a sensing device for detecting travelling direction and transverse position. The links also support cables from an inductive power transfer system installed in the accompanying carriage, which runs on a rail parallel to the test track. The loading vehicle carries eight steel plates, each weighing 20 kN. The load is adjusted by adding or removing plates. The total maximum weight of the loading vehicle with all eight plates is 250 kN.

Loading is controlled so that it is applied in a normal distribution in the range of ±250 mm in order to simulate actual traffic. The maximum running speed is 30 km/h, but the normal operating speed is 15 km/h, which is controlled to an accuracy of 10% or less.

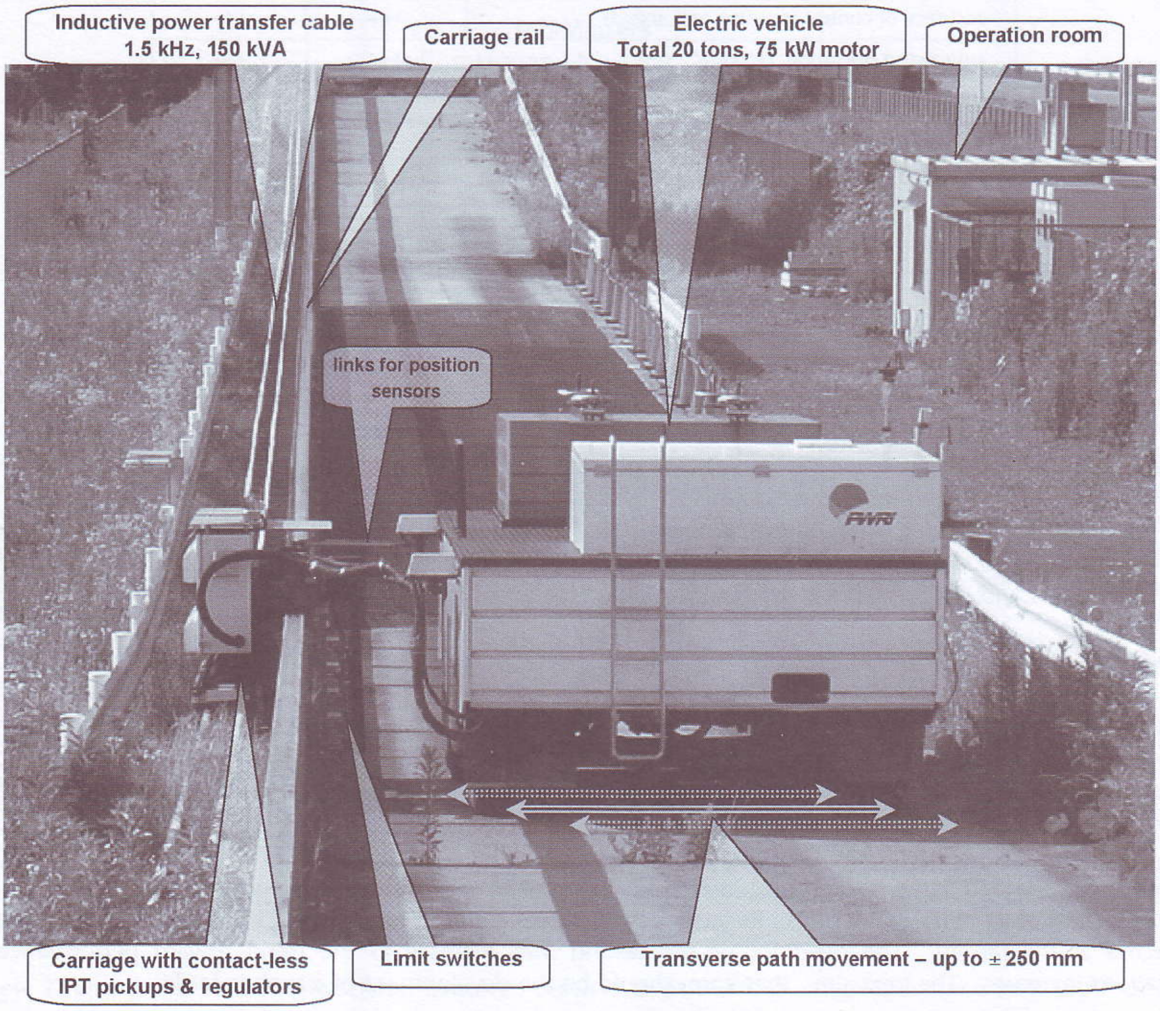


Figure 4: General view of R-APT facility

3.3 Comparison of PWRI Facilities

The objectives of testing are not uniform. In some cases, testing can be accelerated (e.g. high loads) as a means of maximising the use of available resources. In other cases, test conditions need to be less severe, e.g. when a pavement of unknown performance history or a light-traffic application is being evaluated.

Table 5 summarizes the characteristics of the APT facilities at PWRI. Because both facilities are of the fixed type, the pavements tested must be constructed at the facility. The need for on-site testing will increase as the trend toward performance-based specifications increases. The next step, therefore, should be the development of a mobile facility.

The operation of the C-APT facility is efficient because of its long test length and a large number of sections can be tested at the same time. However, when many different sections are constructed along a test track, the need to take measurements on one section will impact on the operation of all sections. Moreover, if a section ultimately fails, then the entire testing operation could be interrupted. The testing of pavements of unknown performance history, or light-traffic applications, should therefore be conducted separately from other pavement types. This type of testing is

probably more suited to the R-APT than the C-APT because, although the test length is short (50 metres) it is more suitable for tests when frequent measurements are needed or when a pavement has to be rehabilitated or the causes of failure examined through trenching.

Table 5 Comparison of Characteristics of APT Facilities at PWRI

	C-APT	R-APT
number of sections per trial	+++	+
availability of vehicle speed	+++	+
acceleration ratio of loading	+++	++
accuracy of control (position and speed)	+++	+++
automated operation	+++	+++
operation cost per trial	++	++
maintenance cost	+	++
mobility to small series testing	++	+++
tolerance to partial section failure	+	+++
applicability to pavement having unknown durability	+	+++

+++: excellent; ++: good; +: weak

3.4 Pavement Materials Evaluated to Date

The main focus of the R-APT facility is recycled materials, which have been tested in tandem with conventional materials as a means of examining their durability. Materials evaluated in the R-APT facility to date include dense-graded asphalt using recycled aggregates, carbonized waste wood aggregate, photo-catalyst-supported pavements for purification of exhaust gas, porous elastic surface layers using waste tyres (precast panels and block pavements), carbon black fillers and thin prefabricated ceramic panels.

4. CONCLUSIONS

The recent trend towards the use of performance-based specifications in Japan has resulted in an increase in demand for full-scale accelerated pavement testing projects. As the public research and consultancy organisation for road agencies, PWRI has enhanced its APT facilities. Two kinds of mutually complementary facilities, a circular type and a reciprocating (linear) type are now being utilised at PWRI.

This paper has provided some background into the development of performance based specifications in Japan and presented details of its two APT facilities. Because both facilities are of the fixed type, the pavements tested must be constructed at the facility. The need for on-site testing may increase as the trend toward performance-based specifications increases. The next step, therefore, should be the development of a mobile facility.

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MEASURING CHIP SEAL SURFACE TEXTURE WITH DIGITAL IMAGERY

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ABSTRACT

Surface texture is the single most important physical characteristic in the management of chip seal surfacings because it is directly related to skid resistance. The development of a method that allows road owners and contractors to enhance the accuracy, reproducibility, and speed of texture measurement task will therefore accrue a large number of benefits, not only to road managers but also to the community. The purpose of the research described in this paper was to evaluate whether a practical method of road surface texture measurement using digital image processing, incorporating information theory and fast Fourier transform (FFT) analysis, could be developed. The results of trials in the USA and New Zealand clearly demonstrated that the merger of digital image processing and physical texture measurements was possible and had the potential to successfully replace the sand circle (sand patch) test currently used. It was also possible to standardise the experimental set-up and calibrate the software and hardware necessary to achieve a high correlation using non-linear regression analysis with a sorted sample population. It is also proposed that the results of this research could be extended beyond texture measurement to the characterisation of skid resistance.

1. BACKGROUND

Surface texture is the single most important physical characteristic in the management of chip seal surfacings because it is directly related to skid resistance. In addition, texture is important in the design of reseals to ensure that the proper aggregate gradation and bitumen content is selected that not only achieves the desired pavement preservation objectives but also improves the physical characteristics of the newly-sealed surface. The development of a method that allows road owners and contractors to enhance the accuracy, reproducibility, and speed of texture measurement task will therefore accrue a large number of benefits, not only to road managers but also to the community.

The New Zealand seal design algorithm requires texture depth of the existing surface as a key input. This texture has been measured using a volumetric technique called the sand circle test (also known as the sand patch test), which consists of spreading, with a straight edge in circular motion, a known volume of uniform-sized sand on the road surface, measuring the diameter of the circular area covered by the sand, and dividing the volume by the area to obtain an average texture depth. Even with experienced, skilled operators, the test takes some time to perform, and is normally done in live traffic conditions with varying levels of traffic control. Even though the reproducibility (40%) of the sand circle test is poor, it is the most common means to measure texture Patrick, Cenek and Owen 2000).

Numerous attempts have been made to use lasers to measure texture (such as the Mini-Texture Meter and high-speed vehicle-mounted lasers used in New Zealand), but as these do not generate a volumetrics-based texture, laser-measured texture cannot be used for seal design. Multiple scanning lasers could feasibly generate volumetric texture, but this would be a very expensive and costly procedure. Transit NZ owns a stationary laser profilometer, which is a precise tool for measuring texture, but this device cannot be used for routine measurements of texture because of the substantial time and effort involved in setting up the device at each test site.

The purpose of the research described in this paper was to evaluate whether a practical method of road surface texture measurement using digital image processing, incorporating information theory and fast

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Fourier transform (FFT) analysis, could be developed. The objectives of the research were to:

- develop an accurate, repeatable method of measuring texture to replace the sand circle method, and
- develop a fast, safe method of measuring texture to reduce the hazards associated with the measurement of road surface texture and to minimise disruption to traffic.

Similar research had been undertaken in Texas, USA, but the focus of the American research was to correlate a qualitative performance rating of the chip sealed surface pavement with a quantitative measure of texture derived from digital imagery (Gransberg, Karaca and Burkett 2002). When a proposal was submitted to conduct experiments to correlate chip seal image FFT numbers to the measured skid resistance, the Texas highway agency was not interested in developing the concept any further. Thus, the aim of this research was to apply the concept for measuring chip seal texture depth in order to replace the present sand circle method of measuring texture in use in New Zealand.

Road users are rapidly becoming less tolerant of travel delays caused by road works, so the research will benefit road users by substantially reducing the time involved in measuring the texture of existing surfaces. Also, society in general is placing more emphasis on worker safety, and one of the potentially most dangerous activities on the road is the current manual measurement of surface texture using the sand circle test; the proposed research aims to significantly reduce the exposure of consultants and contractors to the risk of injury and death while measuring surface texture.

2. DIGITAL IMAGING THEORY

As previously discussed, the technique used in this research project was developed during a research project funded by the Texas Department of Transportation (TxDOT). In that project, the site surveys of representative chip seal sections were conducted in each of the 25 TxDOT Districts in conjunction with a state-wide chip seal constructability review (Gransberg, Senadheera and Karaca 1998). District personnel were asked to pick sections that typified the overall quality of the chip seals in their districts. During each of these surveys, the condition of the roadway was recorded by taking digital camera images. These images not only showed the overall condition of the roadway but also close-up views of the shoulder, wheelpath and the area between the wheelpaths. These images were used to identify an objective parameter that would quantify the quality level of the chip seal surface.

The parameter selected was the information content of each image as calculated by a mathematical transform to be discussed later in this paper. In essence, each image has a finite amount of information contained in its boundaries. This information can be measured by determining the relative change in luminance intensity between adjoining pixels in the image. This relative difference in luminance is called the spatial frequency. For example, if the luminance intensity of one pixel is high and the intensity of the next pixel is low, the difference between the pixels is a large number, and the two pixels are said to have a high contrast and a correspondingly high spatial frequency.

On the other hand, if two adjoining pixels have luminance intensities that are nearly equal, they have low contrast and low spatial frequencies. High contrast occurs at the boundaries between two different objects in an image (Ellis 1976). The relative visibility of an object against its background is a function of the amount of contrast (Cuvalci *et al.* 1999). Thus, in the chip seal image, the contrast is formed by the amount of light reflected off the exposed aggregate compared with the amount of light reflected off the background formed by the asphalt binder (Christie 1954). The study found that TxDOT maintenance personnel could easily discern between a satisfactory chip seal surface and an unsatisfactory one by merely looking at it (Gransberg *et al.* 1998). It was also obvious to the naked eye that the difference between chip seal performance success and failure was linked to the relationship between the aggregate and the surrounding binder. On that basis, it was postulated that the surface condition could be measured by correlating the information content of a digital image and the qualitative rating of the human expert. The use of such an objective metric would significantly facilitate the decision-making process regarding the allocation of the funding to be invested on candidate chip seal sections on the basis of a quantitative comparison rather than a qualitative comparison.

The Image Processing Toolbox of MATLAB ® software (MATLAB 2000; Tang 1999) was used to process the digital images of the chip seal test sections in Texas. The processing of the chip seal images consisted of filtering the information content found in the images and quantifying this filtered information. One way to filter information in such an image is to detect the edges of the aggregate

particles (i.e. focus on the boundary between the aggregate and the surrounding binder). As will be seen later, there are significant differences between the edge patterns of flushed, stripped and satisfactory pavement surfaces. When a sufficiently large population is imaged, and its qualitative performance rating is related to the product of the fast Fourier Transform (FFT) image processing output, a distinct difference can be seen between chip seal surfaces with satisfactory texture and those that have failed either by flushing or shelling.

The potential for associating a quantitative rather than a qualitative texture rating, and being able to regress the relationship between the physical texture measurement and its associated image processing output to derive a formula that allows the engineer to compute the texture measurement from the image output, can be seen in *Figure 1* (Gransberg *et al.* 2002).

3. IMAGE COLLECTION AND PROCESSING RESULTS

A series of limited experiments was conducted using the imaging processing software and protocol on digital images collected on chip seal pavements in Oklahoma in September 2004. The image processing output was correlated with qualitative ratings of chip seal texture to confirm that the new software and hardware could replicate the process published in Gransberg *et al.* (2002).

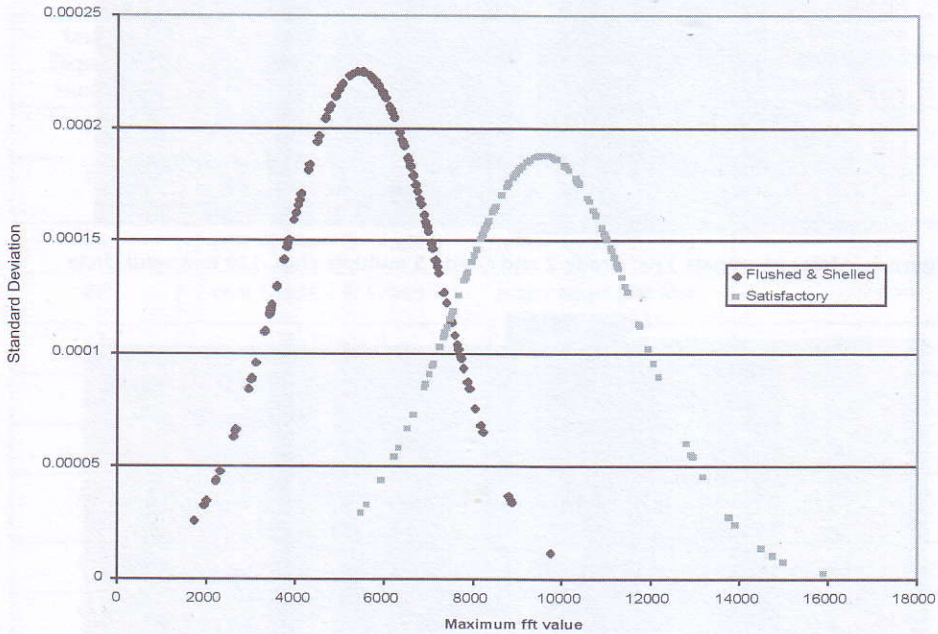

Figure 1: Normal distribution of maximum FFT values for different textures (Gransberg et al. 2002)

Another series of limited experiments was conducted on New Zealand chip seals in October 2004. The output was correlated with sand circle texture measurements taken at the same time and in the same locations as the images. Both linear and nonlinear regression models were developed and the classic statistical measurement of correlation, the coefficient of determination (R^2) computed.

4.1 Proof of Concept

Figures 2, 3 and *4* compare the image processing output derived from the digital images collected in New Zealand with the corresponding image. It can be seen that, in the region of Ring 10 (horizontal axis of left-hand graph in the three Figures) there is a pronounced difference in FFT values. This illustrates the importance of applying this type of analysis to the problem of chip seal texture measurement with a digital camera. Each ring exhibits somewhat different behaviour; this knowledge will be used to enhance the ultimate accuracy of the measurement technique.

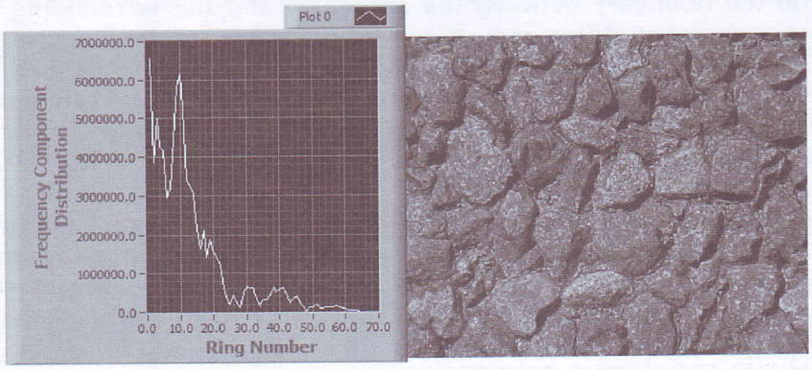

Figure 2: Satisfactory texture; Grade 3 single chip seal, 175 mm sand circle

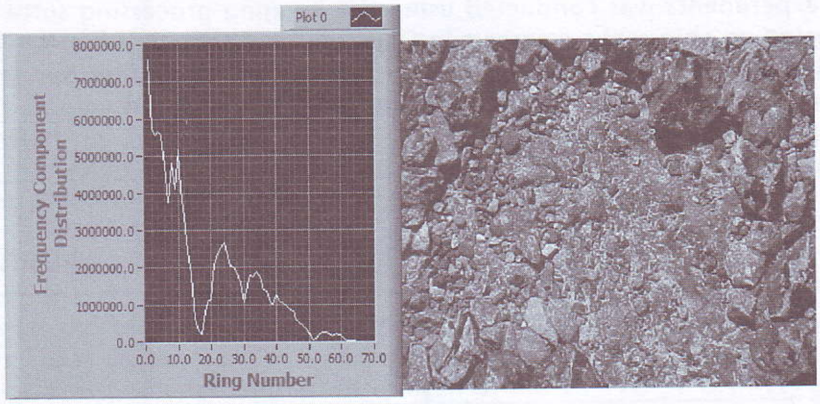

Figure 3: Major aggregate loss; Grade 2 and Grade 5 multiple chip, 120 mm sand circle

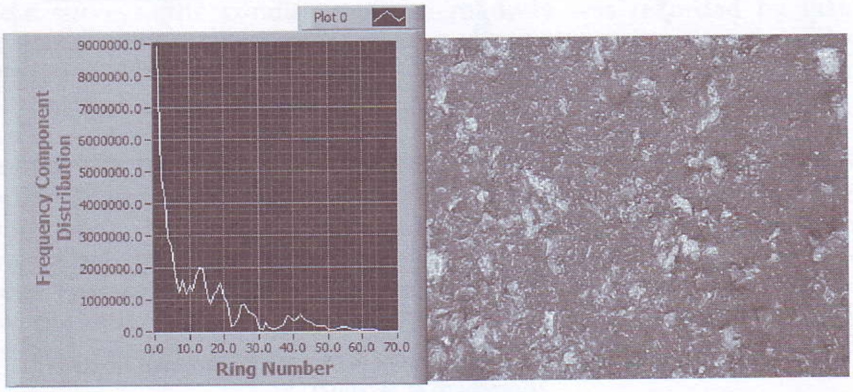

Figure 4: Very heavy flushing; Grade 3 single chip, 300 mm sand circle

The Ring 10 phenomenon needs further explanation. The data shown in *Figures 2* and *4* are for the same size chip taken using the same camera at the same focal length. It can be seen that the FFT value for satisfactory chip seal texture *(Figure 2)* is about 6.1 million whereas, when the surface becomes heavily flushed, the value drops to about 1.2 million and the sand circle measurement nearly doubles between the two images. It is also interesting to note that, in *Figure 3* (the image portraying aggregate loss), the Ring 10 FFT value is less that 5.0 million. While this is a different chip seal design, and hence the comparison is indirect, the concept that the FFT, and hence the information content, should reduce as the amount of visible aggregate-binder edge boundaries decreases is validated. *Table 1* provides the average least dimension (ALD) values used to categorise New Zealand chip grades.

Table 1: New Zealand Chip Grades and their Average Least Dimensions

Grade of Chip	Average Least Dimension ALD (mm)
2	9.5-12.0
3	7.5-10
4	5.5-8.0

4.2 Proof of Principle

The results of image/sand circle testing conducted on a selection of typical New Zealand chip seals, in a range of condition, are presented in *Table 2*. Initially it had been hoped that there would be no need to sort images according to design type as the work in Texas had not been diminished by the inclusion of images that contained not only two different chip gradations but also a combination of precoated and non-precoated chips.

However, the correlations carried out in the Texas study were between a qualitative condition rating and the quantitative output of the image analysis. When the same approach was applied to correlating two quantitative measures for the entire sample population (i.e. the sand circle and the FFT value), the results were less successful.

Figure 5 shows the best correlation results achieved. The coefficient of determination (R^2) of 0.4237 suggested that the FFT accounted for only 42 % of the variation in the sand circle measurements, which was not acceptable. It is interesting, however, that the use of the camera to measure the chip seal resulted in variation approximately the same as the sand circle test.

Table 2: New Zealand Trial Image Sample Population

Image Sequence Number	Design	Texture	Sand Circle (mm)
#2	2-coat Grade 2 & Grade 4	satisfactory	145 mm
#3	West coast Grade 5 variegated colour chip	satisfactory	185 mm
#5	2-coat Grade 2 & Grade 5	minor aggregate loss	150 mm
#6	2-coat Grade 2 & Grade 5	major aggregate loss	120 mm
#7	Single Grade 3	very heavy flushing	300 mm
#8	Single Grade 3	heavy flushing	285 mm
#9	Single Grade 3	satisfactory	175 mm
#10	2-coat Grade 3 & Grade 5 Greywacke	over chipped	160 mm
#11	Single Grade 2	slight flushing	180 mm
#12	Single Grade 2	satisfactory	155 mm

On the basis that the poor correlation was related to variations in the visual data, and that the FFT value is a function of the quantity of edge boundaries in the image, the data for the double-chip seals was separated from the data for the single-chip seals, on the basis that the double chip seals, which are not used in the US, create an image which has a much higher degree of edge boundaries and hence may require to be correlated as a separate group.

The results are shown in *Figure 6*. It can be seen that the correlation improved ($R^2 = 0.63$). The population of single chip seals included one seal that used Grade 2 chips that are larger than the Grade 3 chips used in the remainder of the samples (see *Table 1*). This data point was removed and this resulted in a coefficient of determination (R^2) value of 0.9387 (see *Figure 7*). The demonstrates the potential for a strong improvement in variability using this method compared to the sand circle test method.

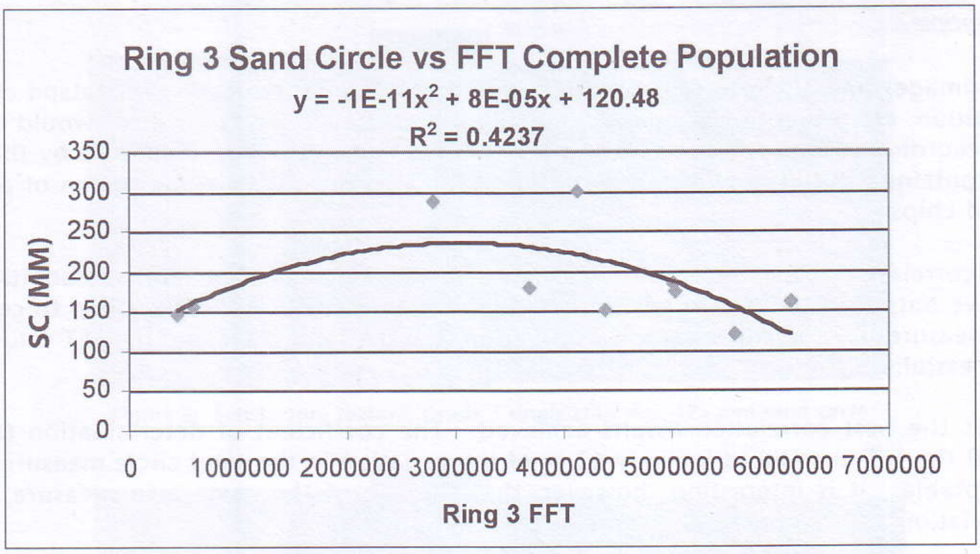

Figure 5: Correlation between sand circle measurement and FFT value (single and double chip seals)

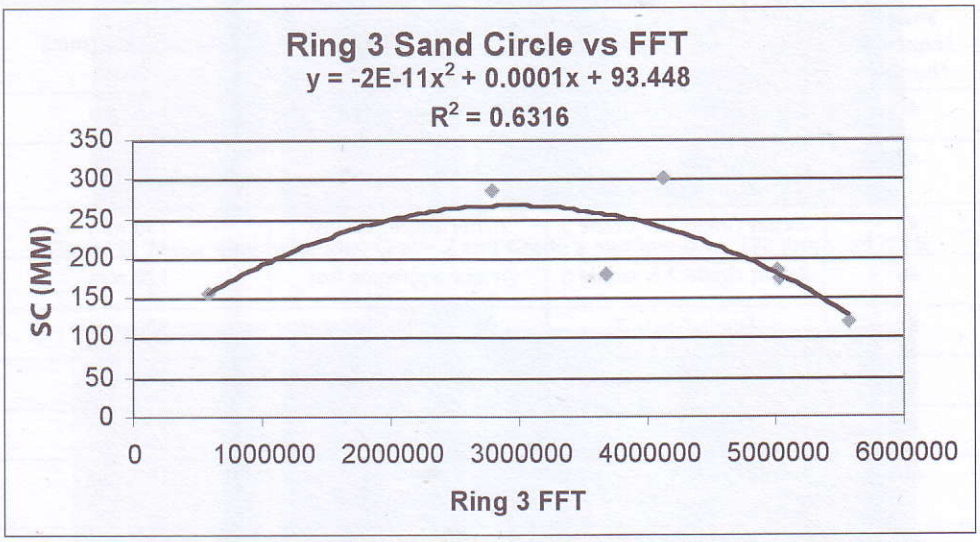

Figure 6: Correlation of sand circle measurement and FFT value (single chip seals only)

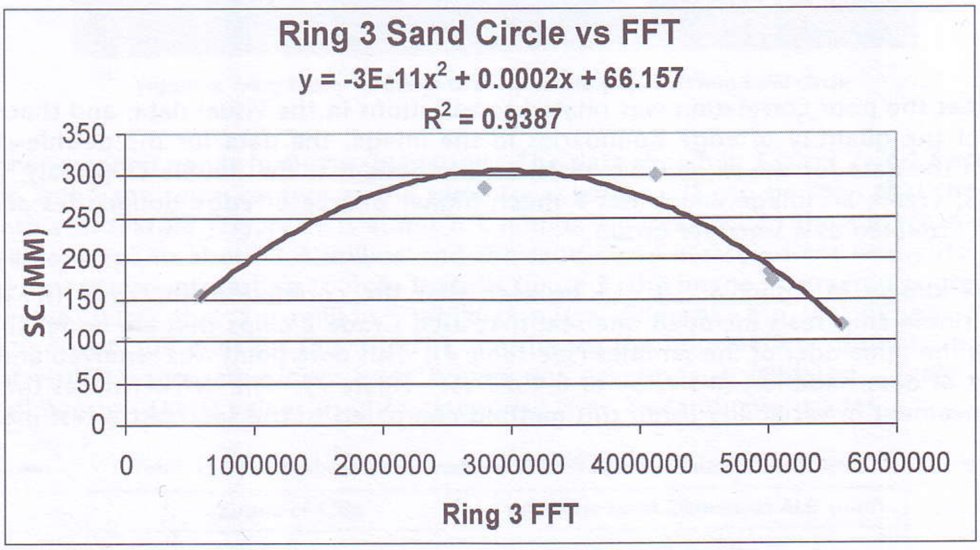

Figure 7: Correlation of sand circle measurement and FFT Value (Grade 3 single seals only)

The data presented in *Figures 6* and *7* also suggest that the same texture could be generated from two different digital image content data values. The results were most significant when the sand circle measurement was converted to average texture depth and the resulting textures depths were regressed against the average of the sum of the FFT values in Rings 1 through 25 (R^2 value of 0.80). As this data contains the majority of the information that is contained in the image group, the results demonstrated that texture can generate a mathematically measurable relationship in a digital image group.

The correlation shown in *Figure 8* is for the situation where the texture component is the independent variable in the regression sequence (i.e. the parameter that was measured in the experiment) and the FFT value is the dependent variable (i.e. the parameter that was predicted from the independent variable). To extend this theoretical finding into practical application the situation would need to be reversed, with the measurement derived from the digital imagery and used to predict the average texture depth of the surface that had been imaged.

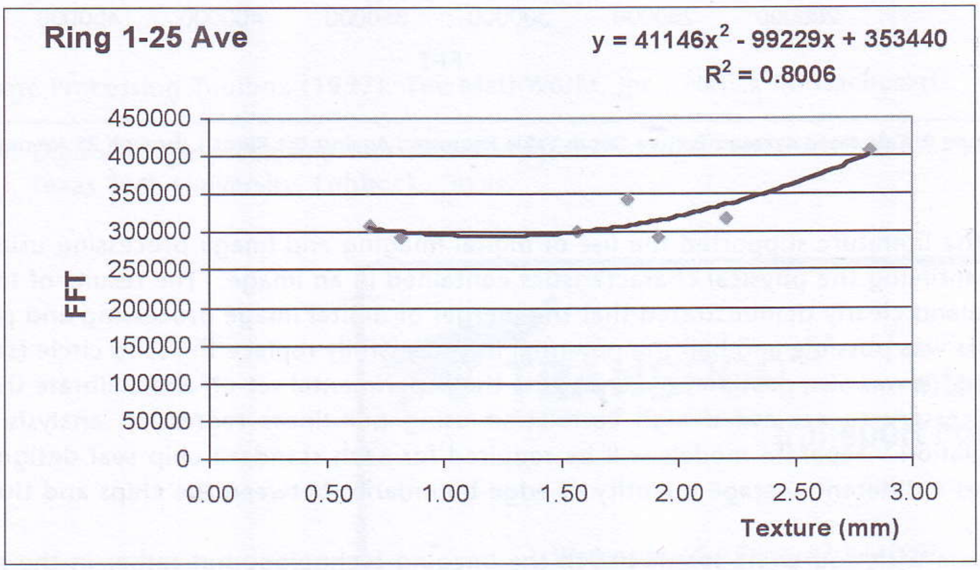

Figure 8: Average FFT regressed against the calculated average texture depth value (Rings 1 through 25)

Figure 9 shows the results when the regression was reversed and the FFT correlated against the texture. It can be seen that a lower R^2 value resulted. The use of higher order polynomials for the regression equation tends to increase the R^2 value for most situations. However, these are not recommended as they generate complex curves that will be difficult to use in field applications. A linear relationship would be preferred to simplify moving this technology from the research to the field application.

5. CONCLUSIONS

This paper has described an evaluation of a practical method of road surface texture measurement using digital image processing incorporating information theory and fast Fourier Transform (FFT) analysis.

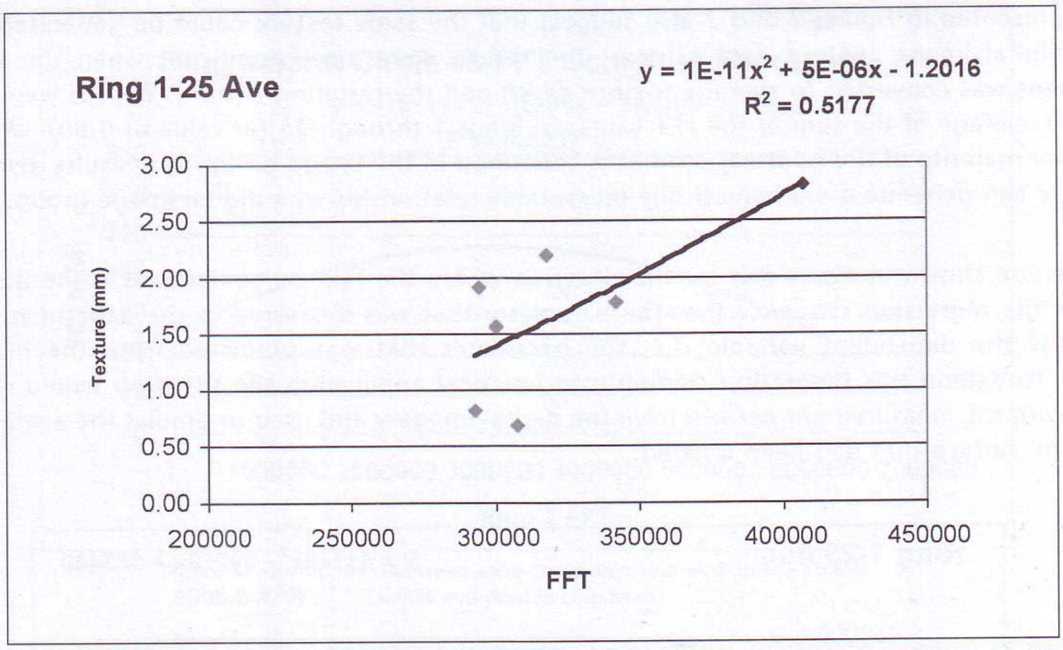

Figure 9: Calculated Average Texture Depth Value Regressed Against the Rings 1 through 25 Average FFT

A review of the literature supported the use of digital imaging and image processing using the FFT as a means of quantifying the physical characteristics contained in an image. The results of trials in the USA and New Zealand clearly demonstrated that the merger of digital image processing and physical texture measurements was possible and had the potential to successfully replace the sand circle (sand patch) test currently used. It was also possible to standardise the experimental set-up and calibrate the software and hardware necessary to achieve a high correlation using non-linear regression analysis with a sorted sample population. Separate models will be required for each standard chip seal design because each design creates a different average quantity of edge-boundaries between the chips and the binder.

The major issue with aggregate loss is not in the imaging technology but rather in the sand circle test where it becomes extremely difficult to accurately apply the test if the 'hole' in which the aggregate is missing is relatively large. This is because the standard volume of sand can literally fail to fill 'hole' and, as a result, no accurate area of sand can be measured. Nevertheless, the technology's ability to accurately measure and correlate the difference been satisfactory texture and texture that is flushed is excellent. It appears, therefore, that the chip seal failure condition that corresponds to a pavement surface condition that is of greatest danger to the travelling public can be directly addressed by the proposed technology.

The next logical stage in this research is to correlate chip seal image output against standard measurements of surface friction. This would provide a fast, inexpensive means of measuring surface friction and improve the ability of road managers to ensure the safety of public roads.

ACKNOWLEDGEMENT

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LTPP STUDY FOR SIX LOCAL GOVERNMENT AUTHORITIES IN SOUTHEAST QUEENSLAND

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ABSTRACT

If pavement management systems are to project forward conditions and costs with any degree of accuracy, then the data that is used to develop pavement deterioration models must be as accurate and appropriate as possible and also collected over a reasonable period of time if due account is to be taken of changing traffic conditions and seasonal variations. A collaborative research and development program between Griffith University, SMEC Australia and six Local Government Authorities in Southeast Queensland is currently being conducted. The main purpose of the program is to calibrate the pavement deterioration factors that are required by the HDM-III deterioration models that have been integrated within the SMEC pavement management system. This paper presents an overview of the research conducted to date, including the procedure for the selection of the long term pavement performance sites and the rationale behind the design of the site selection matrix. Details of the modelling of pavement deterioration using HDM-III at two selected sites are also presented. The pavement distress progression generated by the HDM-4 deterioration models will be compared with those predicted by the calibrated HDM-III models in the next phase of the program.

1. INTRODUCTION

If pavement management systems are to project forward conditions and costs with any degree of accuracy, then the data that is used to develop pavement deterioration models must be as accurate and appropriate as possible and also collected over a reasonable period of time if due account is to be taken of changing traffic conditions and seasonal variations.

A collaborative research and development program between Griffith University, SMEC Australia and six Local Government Authorities in Southeast Queensland is currently being conducted. The main purpose of the project is to calibrate the pavement deterioration factors that are required by the HDM-III deterioration models that have been integrated within the SMEC pavement management system.

This paper presents an overview of the research conducted to date, including the procedure for the selection of the Southeast Queensland long term pavement performance (SEQ-LTPP) sites and the rationale behind the design of the site selection matrix. Details of the modelling of pavement deterioration using HDM-III at two selected sites are also presented. The pavement distress progression generated by the HDM-4 deterioration models will be compared with those predicted by the calibrated HDM-III models in the subsequent phase of the program.

2. CURRENT LTPP STUDIES

In 1987, the SHRP Long-Term Pavement Performance (LTPP) program, a comprehensive 20-year study of the performance of in-service pavements, commenced in the USA (SHRP-LTPP[2]) and Canada (C-SHRP). The study involves the long-term monitoring of more than 2,400 asphalt and Portland cement concrete pavement test sections. The LTPP program was implemented to address 'why' some pavements perform better than others. This information is fundamental to the construction and maintenance of a cost-effective highway system (FHWA 2006).

The Long-Term Pavement Performance Maintenance (LTPPM) study was established in Australia in 1997 as part of an on-going LTPP project being funded by Austroads. The objective of the LTPPM project is to investigate the performance of pavement maintenance treatments under normal traffic loading conditions. Eight sites were established covering a range of climatic conditions and traffic loadings on sealed granular and asphalt pavements in rural and urban areas respectively. The sites were designed in such a way that five maintenance treatment types, of equal segment length, are monitored at each site, making a total of 40 monitored segments (Hoque and Martin 2004).

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[2] *Following the completion of the SHRP Project the US FHWA took over the management of the project. It was then renamed the US-LTPP project.*

In terms of local roads, ARRB has established 580 sites throughout Australia at which pavement performance is being monitored over a five-year period. The sites selected cover a range of roads types, climatic conditions, traffic loading, soil types, construction techniques and maintenance practices (Giummarra 2004). The main objective of the study is to develop appropriate deterioration models for local roads in Australia.

New Zealand initiated an LTPP study during 2000 with the establishment of 63 sites on the State Highway network. The long-term objective of the study is to calibrate the pavement deterioration models currently being used on the State Highway network. These models are a combination of the World Bank's HDM-III and HDM-4 and a number of locally developed models (Henning et al., 2004a and b). In 2003, the study was expanded to include more than 21 local road agencies and an additional 82 sites. By including rural sites and low volume rural roads in the study, the LTPP program now covers the spectrum of pavement construction, traffic composition and climatic zones experienced in New Zealand (Henning et al., 2004*a* and *b*).

3. HDM-III PREDICTIVE MODELS

The HDM-III predictive models have been applied in both developed and developing countries having markedly different technology, climatic and economic environments. Whilst the field experiments initially conducted to develop the models covered a wide range of conditions, there remain local factors that cannot be introduced into the model because this would make the model's input too complex or their effects could not be determined within the ranges observed (Bennett and Paterson, 2000). For these reasons, calibration of the HDM model to local conditions is necessary and recommended. Moreover, if calibration is not carried out the actual pavement deterioration trends and the predicted deterioration may be very different. The lack of an appropriate local calibration can result in an underestimation, or overestimation, of the budget allocation of highway expenditure.

The SMEC Australia Pty Ltd pavement management system (SMEC PMS4) is currently being used to manage over 20,000 km of road, including over 100,000 road sections, for Local Government Authorities in Australia. The road deterioration prediction model used by the SMEC PMS is the World Bank's HDM-III model. A schematic diagram showing the SMEC Pavement Management and Road Inventory System is depicted in Figure 1. The HDM-III pavement condition prediction model is used to predict the future condition of the road sections within the network. The paved road deterioration model in HDM-III includes several variables, the values of which may be input by the user to enable calibration to local conditions. The deterioration model is calibrated for each of three primary distress types: cracking, roughness and rutting.

The data to be collected over the next five years at the LTPP sites described in Section 3 of this paper will provide valuable data for calibrating the HDM models. The specification for the data collection was designed in such a way that the pavement data are also suitable for calibrating the HDM-4 models. A pilot study is being conducted by Griffith University, SMEC and the participating Councils to compare the pavement distress progression generated by the HDM-4 deterioration models with those obtained from the calibrated HDM-III models.

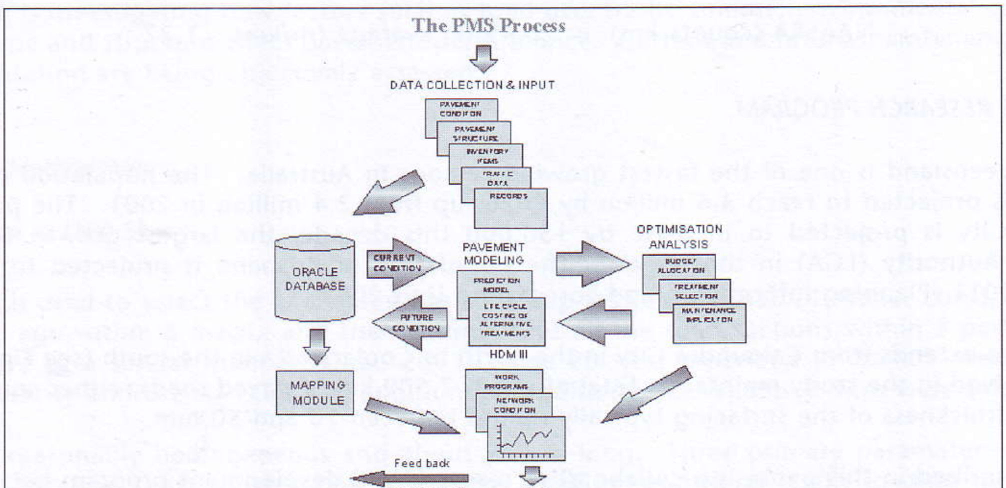

Figure 1: Schematic of the SMEC Pavement Management and Road Inventory System (SMEC 2004)

HDM-III establishes the:

> "causality of events: a pavement starts to crack and to ravel (in a random fashion, after a few years of service); the cracking then increases in extent and intensity; this leads to potholing and other surface disfigurement which, together with rutting, leads to increased roughness – the principal parameter affecting vehicle operating costs" (Paterson 1987).

HDM-III predicts roughness progression as the sum of three components:

- structural deformation, which is related to roughness, equivalent Standard Axle load, and structura number;
- surface condition, which is related to changes in cracking, potholing and rut depth variation; and
- an age-environment-related roughness term.

The HDM-III roughness model is expressed in the following relationship (Watanatada, Paterson and Bhandari 1987):

$$\Delta IRI = Kgp\,[134e^{mt}\,[SNCK + 1]^{-5}\,YE4 + 0.114\Delta RDS + 0.0066\Delta CRX + 0.42\Delta APOT] + Kge\,0.023\,IRI$$

where	ΔIRI	=	predicted roughness (IRI units)
	Kgp	=	user-specified deterioration factor for roughness progression (default value = 1)
	Kge	=	user-specified deterioration factor for environment-related annual fractional increase in roughness (default value = 1)
	SNCK	=	modified structural number for the pavement, reduced for the effect of cracking in asphalt layers
	YE4	=	annual axle loading (million ESA per lane)
	ΔRDS	=	annual increment in standard deviation of rut depth (mm) under a 1.2 m straight edge
	ΔCRX	=	annual increment in indexed cracking (per cent area)
	$\Delta APOT$	=	annual increment in potholing (per cent area)
	m	=	environmental coefficient
	t	=	number of years since last major treatment
	IRI	=	roughness at the start of the year (m/km)

The NAASRA roughness for the lane survey is calculated by averaging the IRI from each wheelpath using the following equation (Austroads 2001):

$$\text{NAASRA (counts/km)} = 26.49\ \text{IRI average (m/km)} - 1.27$$

3. DETAILS OF RESEARCH PROGRAM

Southeast Queensland is one of the fastest growing regions in Australia. The population of Southeast Queensland is projected to reach 3.6 million by 2026, up from 2.4 million in 2001. The population of Gold Coast City is projected to increase by 150,000 this decade, the largest growth of any Local Government Authority (LGA) in the region. The population of Brisbane is projected to increase by 122,000 by 2011 (Planning Information and Forecasting Unit 2003).

The study area extends from Caloundra City in the north to Coolangatta in the south (see Figure 2). The six LGAs involved in the study maintain a total of about 7,500 km of paved roads, either sprayed seal or asphalt. The thickness of the surfacing typically ranges between 10 and 50 mm.

The study described in this paper is a collaborative research and development program between the six local government authorities (LGAs), Griffith University and SMEC. As already mentioned, the six LGAs have adopted the SMEC PMS for the management and planning of their pavement assets and SMEC has

provided its proprietary pavement management software to the University. The study is expected to result in an improvement in both the effectiveness and efficiency of the participating LGA's road maintenance management, and also an enhancement to the tools being used to manage their road assets.

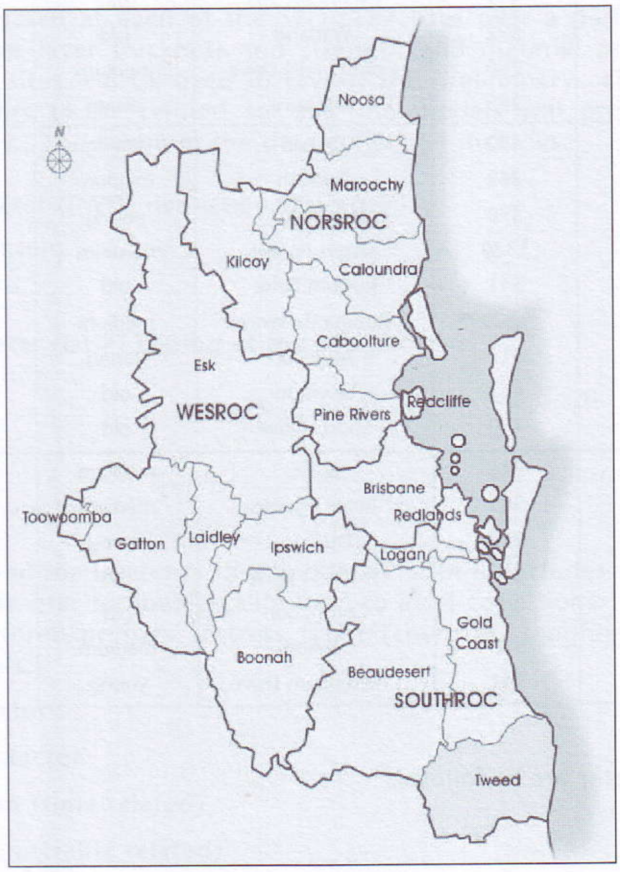

Figure 2: Map of Southeast Queensland (SEQROC, 2003)

The research is investigating how factors such as road use, traffic volume, environmental condition, and pavement type and structure affect pavement performance. Current and future maintenance activities in road rehabilitation are being objectively assessed.

3.1 Research Methodology

3.1.1 Selection of LTPP Sites

The approach used to select the LTPP sites was to group sections of road of similar construction, traffic loading and age within a matrix and then assume that all the road sections within a particular matrix would behave in a similar manner (Chai, 2003). The 25 sites described in *Table 1* were selected by Griffith University and the six LGAs. In addition, an additional 65 validation sites were selected.

Each site is reasonably homogeneous and about 250 m long. Three primary parameters were used to select the calibration sites: construction type (thick, medium and thin); traffic loading (heavy, medium and low) and pavement age (old, medium and young).

Table 1: Details of LTPP Sites

LTPP Site No	Local Government Authority	Length (m)	Road Name	Age	Traffic	Pavement Thickness
1	Caboolture	295	Caboolture River	young	high	thick
2	Caboolture	435	Visentine	medium	medium	thick
3	Gold Coast	650	Dudgeon Drive	old	low	thick
4	Gold Coast	435	Xanadu Court	young	low	thick
5	Redland	434	Panorama	medium	high	thick
6	Logan	439	Chambers Flat	old	high	thick
7	Logan	522	Watland	old	medium	thick
8	Ipswich	280	Commercial Drive	medium	low	thick
9	Ipswich	385	Salisbury	young	medium	thick
10	Caloundra	430	Queen	young	medium	medium
11	Redland	262	Redruth	medium	low	medium
12	Redland	390	Paulina	young	low	medium
13	Gold Coast	1320	Shaws Pocket	medium	high	medium
14	Gold Coast	541	Kortum Drive	old	medium	medium
15	Gold Coast	1520	Robina Parkway	medium	medium	medium
16	Ipswich	317	Augusta	young	high	medium
17	Logan	417	Lawnton	old	low	medium
18	Logan	320	Sports Drive	old	high	medium
19	Caloundra	346	Burys	medium	low	thin
20	Caboolture	385	Avon Avenue	medium	medium	thin
21	Ipswich	255	Duncan	young	high	thin
22	Redland	834	Shore St West	old	medium	thin
23	Logan	500	Coronation	old	high	thin
24	Logan	488	Station	medium	high	thin
25	Gold Coast	941	Cheltenham Drive	young	high	thin

The ranges for each parameter are as follows:

Construction Type:

- thick pavement: total thickness > 400 mm
- medium pavement: 400mm ≥ total thickness ≥ 300mm
- thin pavement: total thickness < 300mm

The calibration sites include both asphalt and sprayed seal surfacings and three surfacing thicknesses (10 mm, 25 mm and 50 mm).

Traffic Loading

- heavy: traffic > 0.30 million Standard Axles/lane/year (MSA/lane/year)
- medium: 0.30 ≥ traffic ≥ 0.05 MSA/lane/year
- low: traffic < 0.05 MSA/lane/year

Pavement Age:

- old: age < 1988
- medium: 1998 ≥ age ≥ 1988
- young: age > 1998

All the calibration sites were selected from areas where no major maintenance (reconstruction or periodic) had been carried out since construction in order that pavement deterioration patterns could be assessed without the influence of pavement works. Wherever possible, different types of pavements were also selected, including foamed bitumen and cemented road base, and sprayed sealed and asphalt surfacing.

3.1.2 Data Collection

For the purpose of calibrating the HDM-III model currently residing in the SMEC-PMS, there was a need to compile a time series of pavement data covering the time the pavements have been in service. The following data is being collected at each of the SEQ-LTPP sites over a period of five years: cracking, rutting, roughness, pavement layer thickness and strength and material properties. The data being collected from the 24 LTPP sites will be used to review the preliminary calibration factors. This will enable the calibration factors to be refined so that the models will predict the actual pavement deterioration more accurately. The scope of the data collection includes:

- Falling Weight Deflectometer (FWD) deflection testing
- Multi Laser Profilometer (MLP) surveys
- pavement coring
- Dynamic Cone Penetrometer (DCP) testing of the subgrade
- visual condition surveys
- traffic surveys.

3.1.3 Calibration Process

As already discussed, the paved road deterioration model in HDM-III includes several variables, the values of which may be input by the user to enable calibration to local conditions. The deterioration model is calibrated for each of the three primary distress types (cracking, roughness and rutting) using the following deterioration factors:

Kci cracking initiation factor

Kcp cracking progression factor

Kge roughness progression (time related)

Kgp roughness progression (traffic related)

Krp rut depth progression factor

The factor Kge determines the rate of increase of roughness due to environment effects independent of traffic loading. The factor Kgp considers the increase in roughness due to traffic loading, rutting, cracking and potholing equally because the latter three parameters are also closely related to traffic loading.

The calibration methodology being adopted in this study is in line with the approach outlined in Volume Five of the *Highway Development and Management* (HDM-4) *Series* (Bennett and Paterson 2000).

Essentially, there are three levels of calibration of HDM-4 models involving low, moderate and major levels of efforts and resources (Bennett and Paterson 2000):

Level 1 – Basic Application: Level 1 is basically a desk-top study of the calibration process. During the desk-top study, many default values are adopted and the most sensitive parameters are calibrated using the guidelines given in the HDM-4 Manual.

Level 2 – Main Calibration: This level of calibration is conducted for the parameters having quality historical data (e.g. roughness, cracking and rutting). Field survey need to be carried out to obtain additional data in order that the key predictive relationships can be calibrated to local conditions.

Level 3 – Adaptation: This involves the undertaking of major field surveys and controlled experiments at LTPP sites to enhance the existing predictive relationships.

During the calibration, the pavement distresses predicted by HDM-III are presented in spreadsheets and the predictions compared with the observed field data. Any necessary adjustment are then made to the calibration factors to make the HDM-III predictions more reasonable. The systematic steps in the calibration process are shown in *Figure 3*.

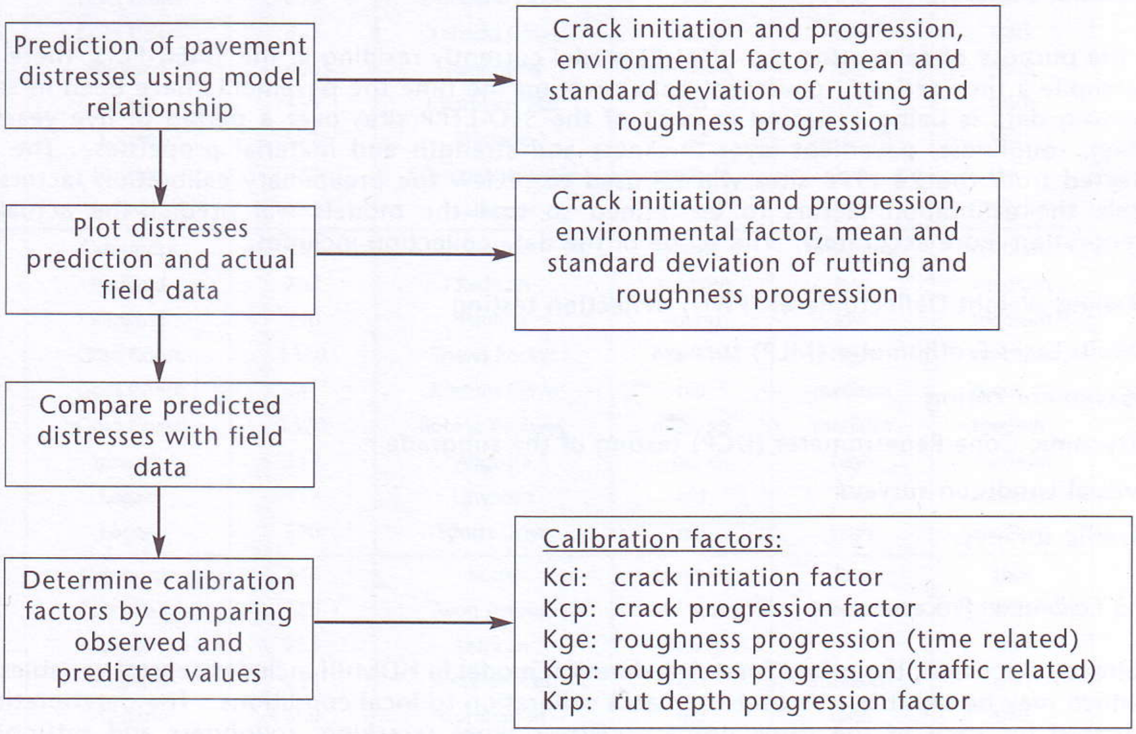

Figure 3: HDM calibration process

4. MODELLING OF PAVEMENT DETERIORATION

Modelling of the pavement deterioration is being carried out using the SMEC PMS and the data collected on the SEQ-LTPP sites. The roughness, cracking and rutting progression data collected on Site 25 (Cheltenham Drive) and Site 15 (Robina Parkway) for the four calibration datasets (see *Table 2*) are shown in *Figures 4* to *11*.

Table 2: Pavement Calibration Factors

Model Description	Dataset 1	Dataset 2	Dataset 3	Dataset 4
crack initiation	0.70	0.90	0.90	1.20
crack progression	0.30	0.30	0.40	0.50
raveling initiation	1.00	1.00	1.00	1.00
roughness-age-environmental	0.60	0.60	1.00	1.20
pothole progression	0.80	1.00	0.80	0.80
rut depth progression	1.00	1.00	1.00	1.00
roughness progression	0.40	0.60	0.80	1.00

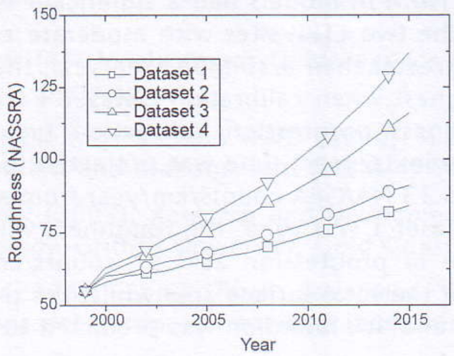

Figure 4: Roughness progression (SEQ LTPP Site No.25, Cheltenham Drive)

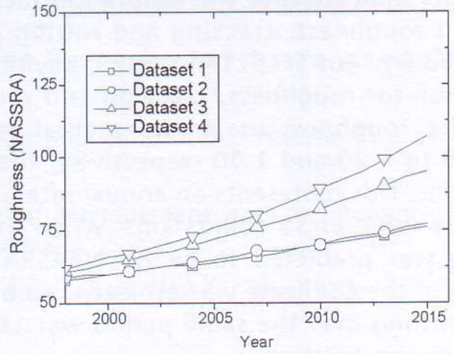

Figure 5: Roughness progression (SEQ LTPP Site No.15, Robina Parkway)

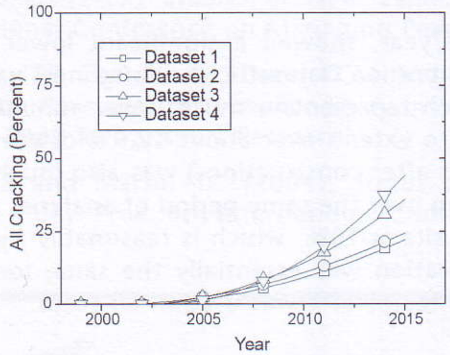

Figure 6: All cracking progression (SEQ-LTPP Site No.25, Cheltenham Drive)

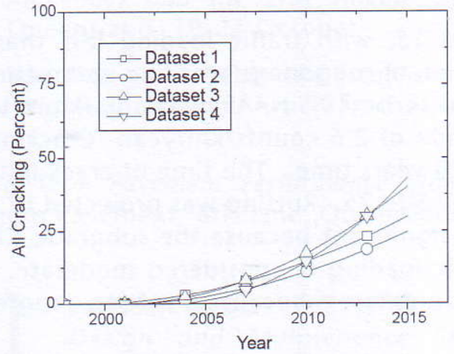

Figure 7: All cracking progression (SEQ-LTPP Site No.15, Robina Parkway)

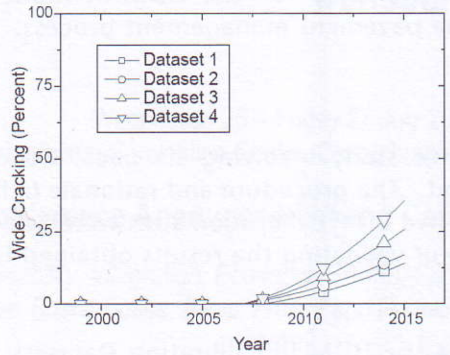

Figure 8: Wide cracking progression (SEQ LTPP Site No.25, Cheltenham Drive)

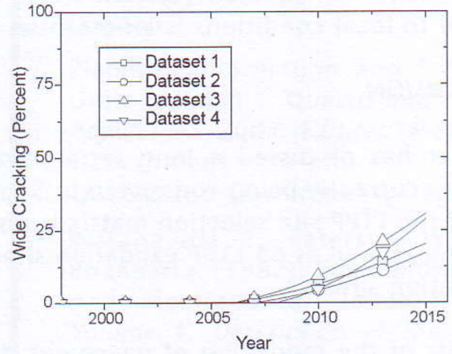

Figure 9: Wide cracking progression (SEQ LTPP Site No.15, Robina Parkway)

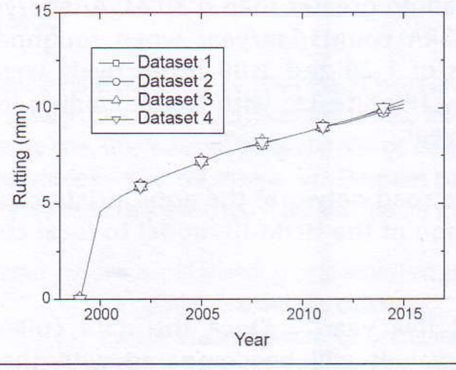

Figure 10: Rutting progression (SEQ LTPP Site No.25, Cheltenham Drive)

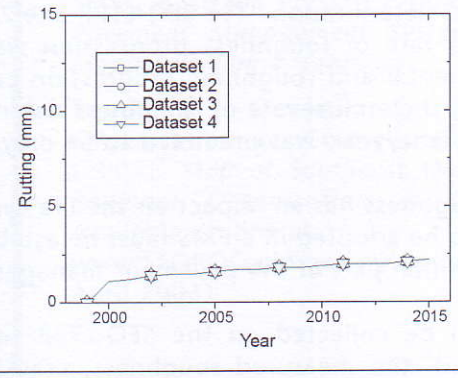

Figure 11: Rutting progression (SEQ LTPP Site No.15, Robina Parkway)

The results indicate that the calibration factors used in the HDM-III models had a significant effect on pavement roughness, cracking and rutting progression for the two LTPP sites with moderate and high traffic loading. For SEQ-LTPP Site 25, having traffic loading greater than 0.30 MSA/lane/year, the rate of progression for roughness, cracking and rutting was the highest when calibration Dataset 4 was used. When the roughness-age-environmental factor and roughness progression calibration factor were increased to 1.20 and 1.00 respectively, the roughness value in 16 years time was projected to be 137 counts/km. This represents an annual rate of progression of 5.13 NAASRA counts/km/year from an initial roughness value of 55 counts/km. When the calibration Dataset 1 was used, the roughness value after 16 years was predicted to be 84 NAASRA counts/km (rate of progression at 1.81 counts/km/year). Cracking of the LTPP site was projected to be about 24.6% of the total surface area whilst the predicted level of rutting over the same period was 10 mm. The time of crack initiation was predicted to be four years after construction.

Examining the deterioration results for the same SEQ-LTPP site using calibration Datasets 2 and 3, the rates of roughness progression were projected to be 2.25 and 3.81 NAASRA counts/km/year respectively.

LTPP Site 15, with traffic loading less than 0.30 MSA/lane/year, showed a significant lower rate of progression of roughness, cracking and rutting. Using the calibration Dataset 4, the roughness value was projected to be 107 NAASRA counts/km after 20 years, which represents a much lower annual rate of progression of 2.6 counts/km/year. Cracking was projected to extend over about 42.9% of the surface area in 20 years time. The time of crack initiation (nine years after construction) was also much longer than LTPP Site 25. Rutting was projected to be less than 3 mm over the same period of analysis. Rutting was not significant because the subgrade CBR value for this site is 10%, which is reasonably high, and the traffic loading is considered moderate. Rutting deterioration was essentially the same for all the calibration datasets because a rutting progression calibration factor of 1 was used in all cases.

It can be seen that the use of different calibration factors in the modelling of pavement performance can yield markedly different predictions of the progression of pavement distress. Since roughness has an impact on the life cycle costing of the road network, the appropriate calibration factors to be adopted in any pavement management system must be established. The need for the HDM-III model to be calibrated to local conditions is an essential component of the pavement management process.

5. CONCLUSION

This paper has discussed a long term pavement performance study involving six Local Government Authorities currently being conducted in Southeast Queensland. The procedure and rationale behind the design of the LTPP site selection matrix is discussed. Twenty-five LTPP calibration sites were selected for monitoring as well as 65 LTPP validation sites for the purpose of validating the results obtained from the 25 calibration sites.

The results of the modelling of pavement deterioration using the HDM-III calibration Datasets 1, 2, 3, and 4 and the data collected at SEQ-LTPP Sites 15 and 25 are also presented. The results serve to demonstrate the effects of different calibration datasets on predicted pavement roughness, cracking and rutting progression. The modelling demonstrated that traffic loading has a significant effect on pavement deterioration. For SEQ-LTPP Site 25, with traffic loading greater than 0.30 MSA/lane/year, the projected rate of roughness progression was about 5 NAASRA counts/km/year when roughness-age-environmental and roughness progression calibration factors of 1.20 and 1.00 respectively were used. However, the annual rate of roughness deterioration for SEQ-LTPP Site 15, with traffic loading less than 0.3 MSA/lane/year, was predicted to be only 2.6 counts/km/year.

Since roughness has an impact on the life cycle costing of the road network, the appropriate calibration factors to be adopted in a PMS must be established. Calibration of the HDM-III model to local condition is an essential part of the pavement management process.

Data will be collected on the SEQ-LTPP sites for the next five years. Once the data collection is completed, the measured roughness, cracking and rutting values will be compared with the values predicted by the calibration datasets. The appropriate calibration dataset will then be selected for adoption by the LGAs once good agreement is established between the measured and predicted values.

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PRIVATISATION OF ROAD FACILITIES

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ABSTRACT

At the 4th meeting of the Heads of Road Authorities (HORA) held in Bangkok, Thailand, in June 2005, each participating country was invited to give a short presentation on their local experiences with the privatisation of road facilities and problems they were facing. This paper presents a summary of these presentations, including the types of schemes operating and problems associated with their use. Many countries expressed the hope that, through REAAA, all countries will benefit from an exchange of information between member countries as a means of improving their knowledge and experience in the privatisation of road facilities.

1. INTRODUCTION

At the 4th meeting of the Heads of Road Authorities (HORA) was held in Bangkok, Thailand, on 15 June 2005, each participating country was invited to make a short presentation with respect to their local experiences with the privatisation of road facilities. These presentation followed the presentation of a paper, *Privatisation of Road Facilities – The Malaysian Experience* by Dato' Haji Ghazali bin Md. Nor, Acting Director General of the Malaysian Highway Authority. This paper briefly describes the road privatisation mechanism, approach adopted and how the recent Asian economic crisis has affected the implementation of road privatisation projects in Malaysia. The paper was published in the 2005 (Volume 2) issue of the REAAA Journal. A summary of this presentation is also presented here for completeness.

2. OVERVIEW OF PRESENTATIONS

In Malaysia, the first expressway project to be privatised was the North South Expressway project, with the concession based on the Build-Operate-Transfer (BOT) scheme. BOT is a process where the private sector receives a concession to finance, build, operate and collect tolls on road infrastructure for a specified period of time, after which ownership of the facility is transferred back to the public sector. Malaysia is not the only country in the Asia and Australasian region which is implementing BOT schemes. Other countries including Bhutan, Pakistan, the Philippines, Taiwan, Thailand, and Vietnam also have road facilities operating under this scheme. BOT projects recently implemented in Pakistan include the improvement of the Karachi-Hyderabad Expressway (M9), the Lakpass Tunnel (Baluchistan), and the Quetta Western Bypass.

In efforts to promote wider private sector participation, the Governments of the Philippines and Vietnam have also passed and amended the existing BOT law and encouraged the participation of private enterprises respectively. Since then, a total of 371 km of new roads have been constructed in the Philippines under BOT schemes. In Vietnam, the introduction of the private enterprise law has resulted in the mobilisation of domestic investment in BOT projects supported with a 40% contribution from the Government.

Apart from BOT schemes, countries such as India, Indonesia, Sri Lanka and Singapore have implemented Public-Private Participation (PPP) schemes. For example, PPP was implemented in the East Coast Road (ECR) project in India in response to constraints in the Government's budget. The ECR was opened to traffic in January 1998, but within 2 years of commissioning, it was showing signs of pavement distress. Irregular maintenance work due to the lack of sufficient

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Government funding led the Government to seek other means of funding. As a result, a 50:50 joint venture between TIDCO and IL&FS, formally known as the Tamil Nadu Road Development Ltd. (TNRDC), was established. In Sri Lanka, the construction of the Colombo Katyunayake Expressway commenced in October 2000 using the design-build-transfer method. In November 2004, however, the contract was mutually terminated and the project recommenced using the PPP scheme with a concession period of 15 years.

In order to improve the participation of private sector in toll road development in Indonesia, the Government amended the Road Law and Land Regulation and developed a plan for a toll road network. According to the latest road law, either the Government, or the Government in partnership with the private sector, can undertake toll road development through PPP.

Unlike other countries, Singapore implemented PPP for the upgrading, construction and maintenance of bus shelters. A number of bus shelters were turned over to a private media advertising company for 20 years; they are given the right to sell advertisement space panels located at these bus shelters. The revenue derived from these sales is used to finance the provision and maintenance of the shelters.

3. SUMMARY OF PRESENTATIONS

3.1 Malaysia

In 2003, Malaysia had a total of 77,200 km of road network infrastructure, of which 75% was paved roads, including 1,490 km of operational toll highways. Traditionally, the development of roads in Malaysia is financed by the Government through its consolidated funds or through borrowing from off-shore sources. However, as the Government faced budgetary constraints and progress in road development slowed, the Government decided to use a direct user charge in the form of toll collection to finance road development.

Privatisation had been introduced in 1977, but it had not been successful due to heavy capital investment and slow return. Subsequently, the Government formed a special-purpose agency, known as the Malaysian Highway Authority (MHA), to undertake this task. The North-South Expressway was identified as the first project in 1981 and, through MHA, the Government was directly involved in the construction and operation of toll highways up to 1988. However, owing to heavy capital outlay and slow capital recovery, the concept of private sector financing through privatisation was reactivated, and the North-South Expressway project was privatised in 1988.

The concession is based on the BOT scheme, where the operation of the completed sections of road was taken over from the MHA followed by the completion of the remaining stretches of road. This privatisation scenario was made possible with the enactment of several Acts of Parliaments such as the Federal Roads (Private Management) Act 1984, which enabled the Government to transfer business to the private sector. By 2005, there were 26 toll concessions awarded to the private sector, of which 19 were already in operation. Most of the toll highways come under the jurisdiction of the MHA with respect to supervision, monitoring and adherence to the provisions of the concession agreements.

Proposals for privatisation of road projects can be initiated by either the Government or the private sector. The proposals initiated by the Government are based on open bidding whilst proposals initiated by the private sector are on a 'first come first serve' basis. The concession companies are responsible for obtaining all the finance, both debt and equity, necessary to construct, operate and maintain the highways.

Privatisation has been successful in Malaysia because of the presence of a well-developed private sector as well as established financial and capital markets. Other contributing factors include the Government's support of, and commitment to, privitisation, clear policies and guidelines, a large pool of capable contractors, investors and technical expertise and, most importantly, public acceptance. Although the toll program was badly affected by the Asian Economic Crisis in mid-1997, the Government has continued to provide support measures to ensure that the program will recover. In 1998, the Government launched the National Economic Recovery Plan to provide a comprehensive framework for economic recovery in the country. In addition, all planned toll highway projects were reviewed and

only viable and priority projects were approved. At the same time, the Government also gained public acceptance of privatised toll highway projects in terms of the toll rate level.

3.2 Bhutan

At present, there are 4,160 km of roads and 4,300 km of mule tracks in Bhutan. The Government first initiated privatisation in 1989, when the construction of a 25 km long road was awarded to the private sector. However, the implementation of privatisation was not totally successful owing to problems associated with contract clauses and their enforcement, the use of inappropriate equipment and the lack of trained operators and supervisors.

The Government then initiated reforms to promote privatisation including the privatisation of state-owned companies, the promotion of institutional and legislative reform, strengthening of the development of domestic skills, the allocation of 50% funding for private sector human resource development and, in 2002, the introduction of approved foreign direct investment policies.

The Government of Bhutan is now looking at options such as study tours and training courses to assist in the development of the private sector, and policy and legislative reform.

3.3 Brunei

Brunei has a total area of 5,780 km^2 and a road network 2,560 km long. Currently, there is only one toll road in Brunei which is managed by the Government. The road network in Brunei is mostly managed under the National Development Plan and has always been funded publicly. Brunei is planning to construct more toll road in other major trunks roads.

3.4 India

The length of the road network in India is 3,315,231 km, including 58,112 km of national highways, 137,119 km of state highways, 470,000 km of major districts roads with the balance (2,650,000 km) being village and other roads. In 1995, the Prime Minister of India initiated the National Highways Development Program, which comprises four components. The total cost of the program is Rs58,000crs (US$1 Dollar = 46 Indian Rupee), with Rs20,000crs being derived from petrol or diesel excess, Rs20,000crs provided by the World Bank and the Asian Development Bank, Rs12,000crs from market borrowings with the balance of Rs6,000crs provided by the private sector.

The State of Tamil Nadu has a total road network of 151,137 km, of which 2.6% is national highways, 4.7% state highways, 4.9% major district roads, 27% districts roads and 60.8% rural roads. The East Coast Road (ECR) was opened to traffic in January 1998. However, within two years of commissioning, the ECR started to show signs of pavement distress. Irregular periodic maintenance activities, or no maintenance, due to State Government budget constraints may have contributed to the deterioration of these roads. As a result, a 50:50 joint venture between TIDCO and IL&FS, formally known as Tamil Nadu Road Development Ltd (TNRDC) was established under the PPP scheme. It was entrusted with improving and maintaining the ECR. The concession agreement was signed in December 2000 and the improvement works commenced in February 2001.

As TNRDC is a 50:50 joint venture, the profits gained from tolling are shared equally between the Government and the private sector. As a result of the concession agreement, the Government has been relieved of the annual and periodic maintenance costs, with the resources now devoted to the social sector or greenfield projects. However, the Government still provides proactive support in all stages of the project life cycle, including assistance in toll compliance and the maintenance of law and order.

3.5 Indonesia

The total length of the toll road network in Indonesia is 660 km. In order to improve the participation of the private

sector in toll road development, the Government has undertaken a number of tasks including the amendment of the road law and land regulation and the development of toll road network planning. Under the latest road law, either the Government, or the Government in partnership with the private sector, can undertake toll road development through PPP. Also stated in the road law are the toll road regulatory functions, which are undertaken by the Toll Road Regulatory Agency (formally known as Badan Pengatur Jalan Tol). While the Ministry of Public Works will continue its role in the planning and development of the highway network, the Toll Road Regulatory Agency will be responsible for the future development of toll roads in Indonesia.

A Toll Road Development Program (2005-2009) was recently developed. It consists of 1,697 km of roads that will require a total investment of about US$14.9B. The road development program includes areas across Java, Sumatera and Sulawesi Island.

3.6 Japan

The four public corporations responsible for the improvement of the national expressway network, the Metropolitan and Hanshin Expressways and the Honshu-Shikoku Highway are the Japan Highway Public Corporation, the Metropolitan Expressway Public Corporation, the Hanshin Expressway Public Corporation and the Honshu-Shikoku Bridge Authority. During the late 1950s, the public corporations launched toll-road projects that utilised loans for road construction with the toll revenues used to pay off the loan.

Even though the nation-wide toll-pooling system, which was introduced in 1972, resulted in significant progress being made in the development of the expressway network, there were still some criticisms, mainly related to the cost of the toll. In response to these criticisms, the four Public Corporations were privatised. The privatisation of these public corporations meant that the interest-bearing debt of ¥40 trillion (US$1 = 115¥) could be paid, and allowed new critical roads to be promptly built at a minimum tax burden.

In addition, the costs of toll-road projects prior to privatization were reviewed, a direct control system on national expressway improvement was introduced, the construction of more interchanges was promoted, and a future scheme of expressway improvement was developed. The management of roads was also separated into regions and an independent administrative entity called the Japan Expressway Holding and Debt Repayment Organisation (JEHDRO) was formed to focus on the repayment of debt. The privatisation of these four public corporations is expected to result in all debts being paid off within 85 years and the expressways transferred to the Government and local authorities.

3.7 Korea

Currently, there are a total of 2,900 km of expressway in Korea, of which 1,600 km was under construction in 2005. Privatisation commenced in 2000 and, by 2005, 17 highway projects had been privatised. Though the privatisation of highways has been practiced since then, there are still some problems. In the majority of cases, private project concessionaires are representatives of construction firms, and the need to reduce project costs is not emphasised, leading to a wastage of already limited funds. In addition, the are complaints from road users, and the national assembly, about the high toll rates of privatised expressways.

Other problems are associated with the lack of efficiency in project management, the lack of experts for project appraisal, project implementation and the different tolling and traffic control systems operating on the various expressways.

3.8 Pakistan

Pakistan has a total road network of 258,000 km, of which 8,885 km are national highways and 2,736 km are motorways. Road infrastructure in Pakistan is predominantly Government owned but, due to the enormous demand for road infrastructure and the lack of sufficient funding and experience, the Government has been obliged to seek assistance from the private sector.

As a result, a private-sector-participation scheme has been implemented for the conduct of road projects throughout Pakistan. The most common method used in privatisation schemes is BOT, where a private sector project company is established as a vehicle for the design, financing, construction and operation of an infrastructure project for a certain period, after which the ownership is transferred back to the public sector. Some examples include the improvement of the Karachi-Hyderabad Expressway (M9), the Lakpass Tunnel (Baluchistan), the Turnol Interchange Rawalpindi (N5), the Faisalabad-Multan motorway (M4) and the Peshawar Northern Bypass. In August 1998, the Economic Coordination Committee (ECC) of the Cabinet of Pakistan accorded an approval of a package of incentives. Among the approved incentives for investments was permission to issue corporate bonds, permission for foreign banks to underwrite shares and bonds, and permission to avail tax concessions available to industry.

3.9 Philippines

The road network in the Philippines is approximately 200,500 km long, of which 15% are national highways, 13% provincial roads, 8% municipal roads, 3% city roads and the remaining 61% 'barangay' or farm-to-market roads. The Government has initiated a number of reforms to improve road management and administration and also to encourage more private sector participation in the national road network. These reforms include the awarding of contracts to qualified and capable construction companies for the maintenance of national roads, the establishment of a dedicated fund for maintenance and improvement projects and reforms to the BOT law to promote wider private sector participation in road construction. The Government is also continuing to promote privatisation by exploring additional funding sources, the introduction of new strategies for the management and execution of road networks, the planning and establishment of a National Road Authority and the reorganisation of in-house engineering services.

3.10 Sri Lanka

The road system in Sri Lanka consists of 11,600 km of national highways, 15,000 km of secondary roads and 65,000 km of rural roads. Current projects in Sri Lanka include the proposed alternate highway to Anuradhapura, the Colombo Katunayake Expressway, the Outer Circular Highway, the Colombo Kandy Expressway and the Southern Transport Development Project.

The Colombo Katunayake Expressway was proposed as a high-speed link between Colombo and Katunayake serving traffic to and from the northern part of the Island. The Expressway is a four-lane road 25.6 km long and includes four interchanges. The construction of the Colombo Katunayake Expressway commenced in October 2000 under the Design-Build-Transfer (DBT) process. In November 2004 the contract was mutually terminated and the Road Development Authority took over the management of the project. The project recommenced using the PPP scheme with a concession period of 15 years. Some of the various construction stages conducted during the previous DBT contract were soft ground treatment and the provision of prefabricated vertical drains, stone columns and sand compaction piles. Approval has recently been obtained from the Central Environmental Authority for the first 25.1 km and the approval for the remaining 0.5 km of the Katunayake end of the project was being sought.

3.11 Singapore

Singapore is an island State having an approximately area of 695 km^2. Traditionally, the upgrading, construction and maintenance of road facilities in Singapore has always been funded by the Government. No private funds were used, nor was there any reliance placed on external loans. However, as the cost of the provision and maintenance of road facilities has continued to increase, particularly for underground road systems, the Government is now exploring means of securing private funding for these works through PPP initiatives.

For example, the Government has recently transferred the management of a large number of bus shelters to a private media company for 20 years. In return, the company was given the rights to sell advertisement space on panels located at these bus shelters, with most of the revenue derived from this advertising used to fund the provision and maintenance of the bus shelters.

The possibilities of using performance-based-contracts for road maintenance is also being explored.

3.12 Taiwan

The presentation from Taiwan concentrated on the participation of private companies in the installation and operation of electronic toll systems. Currently, manual tolling systems are operated at two freeways which are under the operation of the Taiwan Area National Freeway Bureau (TANFB) which operates 22 toll stations. Electronic toll systems are undergoing a transition from manual systems to time-based tolling systems and distance-based tolling systems. The transition from manual to electronic time-based tolling systems does not require the existing toll station to be removed whereas the transition from time-based systems to distance-based systems no longer requires the use of the toll station but the same roadside and On-Board Units shall be maintained.

The main objectives of the implementation of electronic toll systems on freeways are to increase the efficiency in the toll plaza, to promote an Integrated Transport System, to implement distance-based-tolling system and to integrate electronic toll systems (ETC) and ETTM systems.

The ETC system consists of three main parts: the front end, the communication system and the back end. The front end mostly addresses identification and transaction processes and the enforcement of any violations. The back end handles billing management, customs service, the processing of violation, system monitoring. It also provides general support for traffic management. The communication component, the most important entity, is responsible for networking between the front end and back end and interfacing with the traffic management and integrated transport system applications.

In developing the most applicable laws and privitisation regulation processes, both the Government Procurement Act and the Law of Promotion of Private Participation in Infrastructure Projects (LPPPIP) were considered. LPPPIP was adopted because of its flexibility and the fact it required less Government funding. The Far Eastern ETC Company was awarded the contract for the construction and operation of the system. When the concession period is reached, all necessary facilities and the rights of operation will be transferred back to the TANFB. It is hoped that, by 2010, all freeways in Taiwan will be equipped with the distance-based tolling system.

3.13 Thailand

Over the past 30 years, Thailand has continuously invested in infrastructure projects at an average rate of 5% to 6% of Gross Domestic Product annually. However, in response to the growing gap between infrastructure needs and the availability of fiscal funds, the Government has turned to privatisation as a solution to this problem.

The most common method of privatisation is the BOT scheme, which currently operates in most toll roads in Thailand. Two primary projects which were implemented by the privatisation scheme are the Second Stage Expressway (SES) and the Don Muang Tollway (DMT). The privatisation of the SES commenced in 1987, when a Terms of Reference was issued by the Expressway and Rapid Transit Authority of Thailand seeking private sector investment in the design, construction and operation of the SES. In 1988, the BOT concession for the 32 km long SES was grant to the Bangkok Expressway Consortium, which later became the Bangkok Expressway Company Limited. A 30 year concession agreement was signed involving 3 years for construction and 27 years for operation. The SES was opened to traffic in 1993.

Another project which implemented the BOT scheme is the Don Muang Tollway (DMT), which is an elevated road link, 21.9 km long, operating between the central part of Bangkok and the Don Muang International Airport. Because of the huge investment required but severe budget constraints, the Government adopted the BOT scheme as a solution. Three companies were selected to build and operate the DMT project: DYWIDAG (a German firm), Delta Construction (a Thai construction company) and GMI (a French contracting company). A 25 year concession was signed in August 1989. The first part of the DMT opened to traffic in December 1994 and was completed by December 1998. Other future privatisation projects in Thailand are the Inter-City Motorway Project and the Bang Yai-Ban Pong Motorway Project.

3.14 Vietnam

As a result of many years of continuing war, the road infrastructure in Vietnam was in poor condition. Insufficient funding and the general state of underdeveloped technology made it impossible for the Government of Vietnam to rehabilitate and further develop their road system. However, in 1990, the Government introduced a 'renovation' and 'open door' policy to fund a series of construction and rehabilitation road infrastructure projects. As a result, considerable progress has been made in improving the transportation sector. Today, Vietnam has a road network 223,290 km long, including 17,295 km of national highways, 21,763 km of provincial roads, 45,014 km of district roads, 124,942 km of village roads, 6,654 km of urban roads and 7,622 km of special roads. The road network in Vietnam mostly consists of one- or two-lane roads; four-lane roads are very rare.

The first expressway is currently being constructed in the vicinity of Hanoi and Ho Chi Minh City. At present, the road network assets, as well as the land, is owned by the State. This means that every economic sector in the country has the right to utilise the land, whilst paying the tax for its use. They also have the right to construct infrastructure using their own funding; in this case they own the infrastructure for a period of 50 years or more.

However, an increase in demand for more funds to further modernise the road infrastructure has led the Government to seek other solution including privatisation. In order to promote privatisation as a method of funding new projects, a new Enterprise Law will be created. The new law will include equitisation of state-owned transport enterprises, and the mobilisation of domestic investment through BOT projects including a 40% contribution from the Government. An example is the Rach Mieu Bridge Project: various sectors are being encouraged to build and operate bus stations, roadside stations, goods transit warehouses, etc. alongside the road. Toll collection on some national roads is also being transferred to the private sector.

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TRAFFIC OPERATIONS IN EUROPE: SUMMARY OF YOUNG ENGINEERS TOUR [1]

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ABSTRACT

During October 2005, young professionals representing State Road Authorities in Australia and New Zealand toured several European countries to discuss and inspect the latest traffic management techniques and systems in these countries. The focus of the trip was the task of operating the road system and the initiatives that are being used to maximise the efficiency of the network. This paper presents a summary of the findings of the tour. It is suggested that a number of initiatives could be considered for adoption in the region if not already implemented.

1. INTRODUCTION

During October 2005, young professionals representing State Road Authorities in Australia and New Zealand toured several European countries (France, Sweden, Austria, Germany, Wales and England) to discuss and inspect the latest traffic management techniques and systems in these countries. The intention of the tour was to improve each officer's appreciation of traffic management techniques and to enhance the collective Australian position on many of the initiatives used in key European countries. The focus of the trip was the task of operating the road system and the initiatives that are being used to maximise the efficiency of the network. The key functional areas of interest included:

- traffic management strategies and policies
- motorway management systems
- road safety
- road pricing (congestion charging and toll management)
- urban traffic control
- traffic management centre operations
- special road users (public transport, pedestrians, cyclists)

This paper presents a summary of the findings of the tour. It is believed that the trip met all of its intended objectives and will serve as a great development experience for all those that attended. It is envisaged that some of the systems, practices and techniques observed will have direct relevance in Australasian conditions. With the experience and contacts made, the tour members will be in a position to drive relevant changes through their respective organisations.

2. MAIN FINDINGS

2.1 Traffic Management Strategies & Policies

Environmental (including noise reduction) and community liveability issues are gaining increasing importance in driving the transport strategies and policies in many European countries. Environmental issues were particularly important in Wales, Germany and Austria and community liveability issues in central city areas was shaping the transport policies in Paris, Stockholm and London.

The focus in the countries visited was on achieving effective road hierarchies to separate the various traffic types (from high speed inter-regional traffic on motorways to local trips on local streets). This was being effectively handled in many of the countries visited, particularly Germany and Austria. There was a strong commitment to managing cars balanced with catering for special road users (including buses, freight, pedestrians, cyclists, etc.).

Substantial congestion was observed in many of the larger cities throughout Europe. Whilst mechanisms were in place to limit this congestion, there is an increasing focus on managing this congestion. This included informing motorists of the conditions and congestion that may influence their journey to assist them to make informed decisions regarding their route and mode choice.

Many European transport agencies work closely with private industry in the management of the traffic system. This was evident in the development of new technologies (such as 'in-vehicle telematics') through to commercial arrangements to operate Traffic Management Centres. These arrangements appeared to increase the expertise and foster systems more capable of operating the transport network.

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2.2 Motorway Management

Many authorities have sophisticated motorway control systems to manage the high traffic flows on their motorways. These systems are also used to maximise safety of the motorway network. Variable speed limit and lane control systems are common across Europe, actively controlling the status of the lane and the speed limit. This is useful in advising motorists of the upstream traffic and weather conditions and the safe operating speed. They are also used to manage motorway noise and reduce speed if noise becomes a problem for adjacent landholders.

The use of real-time traffic control on motorways is resulting in an increase in compliance with traffic messages. Fixed speed signs and inappropriate real-time messages have been less effective with motorists often ignoring the messages.

Integrated and open architecture traffic control systems are adopted in cities areas as Wales, where a standard open architecture for all of the ITS equipment has been adopted. This allows interoperability of the system and off-the-shelf purchasing of new and/or replacement equipment. This approach was considered to be an effective and leading-edge system architecture.

The unlimited speed limit for sections of the German autobahns appeared to work well though it was noted that this was only permitted on very high standard motorways, mostly with real-time traffic control. The relative accident rates for such motorways were not investigated though it was noted that the driving patterns produced relatively consistent driving behaviour. Driver behaviour patterns observed on German autobahns included:

- vehicles only allowed to overtake on the fast side (that is, vehicles only overtake on the left for left-hand driving conditions) with no undertaking permitted;
- trucks are not permitted in fast lanes; and
- adherence to the required lane discipline between trucks and faster road users.

These rules/driving norms allow separation between different classes of vehicles and assists in the control of the speed differential on motorways. Orderly traffic flows are enhanced through a substantial investment in real-time traffic control with lane control systems to manage incidents and road events.

The use of standardised road hardware (e.g. gantries, variable message signs, etc.) was noted as an effective means of providing consistent messaging to the motoring public. The standardisation was also reported to reduce maintenance costs of this infrastructure.

2.3 Road Safety

Road safety was an important issue in all areas visited. The Swedish 'Vision Zero' policy, which has had a high profile for some years, has achieved good results with substantial reductions in fatalities in Sweden. This is achieved through high level community engagement, safer vehicle engineering (influenced by the Swedish Government buying vehicles with safety measures fitted), engineering measures (e.g. reducing the energy potential of crashes), and legislative measures through initiatives such as a 0.02 alcohol limit. It was noted that user behaviour and legislation alone cannot solve the road safety problem; it must be augmented and complimented by engineering of the vehicle and the transport system.

The aim of 'Vision Zero' is to reduce, and ultimately prevent, all fatal accidents. It was acknowledged and accepted that the Swedish Transport Authority's focus on reducing road fatalities may not affect the total accident rate. Thus they may choose solutions that reduce/eliminate more serious accidents that do not alter the total accident rate.

The use of forgiving roadside environments and reducing the severity of accidents (through increased use of roadside barriers, etc.) is a key initiative used in many areas throughout Europe and substantial reductions in road-related accidents are resulting.

2.4 Road Pricing (Congestion Charging and Toll Management)

Road pricing is used extensively throughout Europe to fund higher quality transport services (e.g. Germany), to assist in the management of congestion (e.g. London) and to improve the liveability of cities (such as that proposed in Stockholm). The technology and systems used to manage congestion charging vary. The charging systems are largely automated with no need for the driver to stop and pay direct tolls, which may cause unnecessary congestion. The road pricing systems used in these countries were reported as having a high community acceptance assisted by strong political backing and non-intrusive automated tolling systems.

2.5 Urban Traffic Control

Urban traffic control was a large issue in the cities visited, particularly London and Paris. Policies to manage traffic focussed on providing relatively simple solutions to actively manage congestion. The level of congestion in peak hours

necessitated a focus on congestion management rather than queue progression. For example, in Paris CBD area the maximum cycle time used is 90 seconds and few protected turn lanes are provided. This means that motorists who wish to turn need to plan their trip in such a way that they do not need to carry out a key turn at major intersections.

The urban traffic control function is linked to each city's design and layout. There was a tendency in the larger cities (including Stockholm, London and Paris) to balance the available road space in the cities between all road users. Cycle times in highly urbanised areas were shorter with simple phases to facilitate bus movements, pedestrian and bicycle users.

The management of planned and unplanned events to minimise the congestion levels was a significant focus of all areas visited. The extent of this task and the monitoring and site management varied across the cities. In Paris there was limited closed circuit television (CCTV) coverage and site management was undertaken by the Police, whereas in London there was significant CCTV coverage to monitor the traffic conditions.

Downstream loops were used in France; they were reported as being more reliable than upstream loops for reporting traffic conditions.

2.6 Traffic Management Centre Operations

Traffic Management Centres (TMC) provide a high level of service to the motoring public though the techniques used varied between centres. They have strong mandates and apparent strong organisational backing to actively direct and manage traffic around the transport system.

There was a spectrum of management structures running the TMCs visited, including privately-run TMC operators (such as in Austria and the English National Traffic Control Centre in Birmingham), consortia between private and government (Wales) or partnerships between various levels of government (Stockholm). Regardless of the ownership structure most of the TMCs had strong branding and commitment to their traffic operation objectives. The TMCs that were operated by private companies (e.g. Serco for Birmingham's National Traffic Control Centre and Asfinag in Austria) appeared to work well to enhance the business focus of the TMC functions.

The TMCs visited all had relatively sophisticated communication systems and systems integration (including some with digital video management). The Welsh video distribution was quite advanced and provided increased flexibility for CCTV image distribution and this could be adopted as a model TMCs in the region in their migration towards high quality digital video management systems.

The co-location of functions in TMCs (for example, locating traffic officers with Police and bus operators in the one centre such as the London TMC) appeared to improve the responsiveness to incidents and the relationships between authorities and provide synergies between traffic management, congestion and public transport functions.

The intelligence gathered by the TMC included CCTV images, vehicle detectors (either through in-pavement detectors, video detectors, automatic number plate recognition), information from other authorities and road users. The Munich TMC relied on acquiring most of its information from vehicle detectors whereas the TMCs in England and Wales relied on CCTV images. Most of the agencies visited suggested that the way this information was collected did not matter provided the information was high quality and able to be processed and distributed in a timely manner. The focussing on collecting quality data was a key observation from all of the areas visited.

The level of system automation was very dependant on the size of the network and tasks undertaken at the TMCs. For relatively small motorway network, a highly manual traffic management system was sufficient. An example was short lengths of motorway in Cardiff, which relied heavily upon operators viewing CCTV cameras. However, for larger networks, this was unsustainable; Austria, for example, is working to automate as much of their operation as possible (one centre caters the whole country's motorway system).

2.7 Public Transport, Freight, Pedestrians, Cyclists

A strategic focus is placed on cyclists, public transport and pedestrians in most areas and there are many priority systems used to ensure their safety on the road network. Public transport has a high focus: up to 75 per cent of commuters use public transport during peak periods in cities such as Stockholm. This high level of patronage allows a more efficient transport system which is facilitated by the provision of high quality public transport and some demand management as most of the competing road corridors are congested during peak periods.

The use of shared vehicle/pedestrian zones and pedestrian malls are common in the centre of the major cities to improve the liveability of these centres. Cycle facilities are also very common in most European countries; they are provided to encourage road users to utilise this transport mode. Often these facilities are deliberately provided at the expense of single occupancy vehicle capacity to enhance the liveability in the cities.

The use of partnering arrangements with industry was observed in some countries to facilitate changes in the desired transport outcomes. This was noted in France were the transport agencies were working with freight companies to maximise the efficiency of freight transport to reduce road congestion and environmental impacts.

3. CONCLUSIONS

It is suggested that the following initiatives could be considered for adoption in the region if not already implemented.

- Implement the experience gained from the use of the 'vision zero' approach, including the provision of more forgiving roadside environments to reduce high energy accidents.
- Increased use of variable speed limits and lane control systems on motorways to improve safety and capacity.
- Further development of multi-jurisdictional Traffic Management Centres, including commercial arrangements to increase the level of service of these centres.
- Further development of standards to achieve consistent ITS systems and provide more reliable traffic data to the public.
- Increased government/industry partnerships and encouragement to the ITS industry to develop a higher standard of ITS services.
- Consideration for more legislation and/or education of drivers to promote the more efficient use of motorways (e.g. allowing overtaking only on right on multi-lane roads).